

36/c

THE
ELEMENTS
OF
Natural Philosophy.

Chiefly intended for the Use of
STUDENTS in UNIVERSITIES.

BY
PETER VAN MUSSCHENBROEK, M.D.
Professor of MATHEMATICKS and PHILOSOPHY
in the University of *Leyden*.

Translated from the Latin

BY
JOHN COLSON, M. A. and F. R. S.
Lucasian Professor of MATHEMATICKS
in the University of *Cambridge*.

V O L. II.

L O N D O N :

Printed for J. NOURSE, at the *Lamb*
without *Temple-Bar*.

M.DCC.XLIV.



C O N T E N T S

O F T H E

S E C O N D V O L U M E.

C H A P. XXVI.	Page
O F F I R E	I
C H A P XXVII.	
<i>Concerning the general properties of light</i>	49
C H A P. XXVIII.	
<i>Of refracted Light</i>	59
C H A P. XXIX.	
<i>Of light falling upon the plain and spherical surfaces of refracted media</i>	71
C H A P. XXX.	
<i>Of light passing out of air into glass, and thence again passing into air</i>	79
C H A P. XXXI.	
<i>Of the different refrangibility of the rays of light, of and colours</i>	85
C H A P. XXXII.	
<i>A description of the Eye</i>	97
C H A P.	

CONTENTS.

CHAP. XXXIII.

*Of the passage of light through the humours of
the eye, and concerning vision* 106

CHAP. XXXIV.

DIOPTRICKS 125

CHAP. XXXV.

CATOPTRICKS 136

CHAP. XXXVI.

Of the Air 159

CHAP. XXXVII.

Of SOUND 194

CHAP. XXXVIII.

General matters concerning aerial Meteors 220

CHAP. XXXIX.

Of watry Meteors 234

CHAP. XL.

Of fiery Meteors 278

CHAP. XLI.

Of airy Meteors, or of Winds 306

THE



Natural Philosophy.

CHAP. XXVI.

Of FIRE.

§. 760. **T**HE famous *Boerhaave* has treated so completely concerning fire, that we have little else to do but to repeat the same things after him, to which little can be added. Because fire, by it's extreme subtilty, escapes almost all our senses, and is always present in every place, and in every body, in which we can make any experiments, it will be very difficult to discover those characters which are peculiar to it. These can be only derived from the phænomena it produces, where it is present in a greater or lesser quantity than before. These characters seem to be only two, *light* that affects our sight, or a greater or less *rarefaction* than before, of bodies either fluid or fixed. One or other of these characters we make necessary, because

VOL. II.

B

there

The ELEMENTS of

there may be fire that does not separate or attenuate bodies, but only shines; such as the light of the moon, which though collected by means of a burning glass or speculum, does not act upon the nimblest Thermoscope. And there is fire also, the light of which is not perceivable, but yet it rarifies bodies; such as is in water, or bubbling oils, or in metals not yet in fusion. For these are rarified, and yet they do not shine. The intumescence of bodies is not an infallible sign of fire being entered into them, because water and moist air entering into any vegetables will make them swell; yet it does not penetrate into all bodies, as fire does, which rarifies all things.

§ 761. Whatever firm bodies have been examined, are found to be extended by fire in all their dimensions, as long as it remains in them. This is demonstrated to sight by the assistance of our Pyrometer^a, which shews the rarefactions of bodies, which are no more than $\frac{1}{12500}$ part of a *Rhenold* inch, which I call degrees. The bodies examined are all metal, semi-metals, many sorts of stones, white chalk, burnt bricks. All these are rarified by fire, not in length only, but in their other dimensions also. This we prove by help of a brass cone, which when cold, does but just pass through a hole, and when hot will not pass at all.

§. 762. Every body, by a determinate quantity of fire, is extended to a certain bigness; and is so much the more extended, as it is exposed to a more copious fire, yet to a certain constant degree only^b.

§. 763. If cold bodies are exposed to the fire, at first they are rarified but slowly, then faster,

^a Comment. Tentam. Florent. part. II. p. 12.

^b Tentam. Flor. part. II. p. 16.

and then very fast; again but slowly, and afterwards more and more slowly, the nearer the bodies approach to their greatest expansion, which they can receive from the same fire^a. For fire does not so easily enter the narrow pores of cold bodies, as it does when they are something enlarged. But when the parts have something receded from one another, they have a greater reluctance than before, against any farther recess, the dilating force of the fire remaining the same. Besides from the enlarged pores the fire goes out more easily, by which the rarefaction is continually diminished, the same quantity of fire approaching, till at length it stops by the force of coherence, or the attraction of the parts being *in equilibrio* with the expanding force of the fire.

§. 764. The same fire, when it rarifies different firm bodies, does not expand them in a reciprocal ratio of their weights, nor in a reciprocal ratio of their coherences, nor in a ratio compounded of these two, but without any rules that have been yet discovered, as we have proved by experiments. For by the same fire was rarified red copper 89 grains, brass 110, iron 80, lead 155, pewter 153, silver 78. But the coherences or firmnesses of red copper are as 229,5, of brass as 360, of iron as 450, of lead as 29,25, of pewter as 49,25, of silver as 370, by §. 564. Therefore the rarefactions are not in the inverse ratio of the firmnesses. They seem to depend on the different orders that compound the parts, on the magnitude, the multitude, and figure of the pores, the hardness, softness, elasticity, and the tenacity of the parts, on the quantity of the oil or sulphur which can receive, retain, and feed the fire more plentifully; of all which we are ignorant.

^a Tentam. Flor. part. II. p. 24, &c.

The ELEMENTS of

§. 765. Different firm bodies do not begin alike to be dilated by the same fire; among metals pewter is soonest rarified, then lead, then silver, brass, red copper, and lastly iron^a.

All which depend on the different structure of the pores, by which the bodies admit the fire with more or less facility, or attract it, or repel it. As also on the various cohesion of the parts, their structure, porosity, and magnitude.

§. 766. Metals and semi-metals may be so far rarified by fire, as that the parts may be separated from one another, may be dissolved and so may be liquified into a fluid mass. But all metals do not require the same quantity of liquifying fire to be reduced from the same degree of cold to a fluid state, but some require a greater, and some a lesser quantity. Pewter from the coldness of ice being heated to fluidity, rarifies iron 109 degrees in our Pyrometer. Lead rarifies the same iron 217 degrees, bismuth 300, and golden marcasite 169 degrees.

§. 767. As metals are reduced into fluidity by fire, so it is with other bodies, as wax, pitch, sulphur. This action of fire is called *melting*, or *fusion*. In this the force of fire, separating the parts of bodies, overcomes that force by which the parts cohere, so that they are generally dissolved from mutual contact, and swim about in the fire. For as long as they mutually touch one another, they will still cohere.

§. 768. There are certain bodies which very hardly, if at all, are reduced to fusion, by terrestrial fire, yet if another body be added, the fusion is promoted. Thus all earths, which of themselves cannot be melted by the most vehement fire, by the help of alcalinous salts, are turned

^a Tentam. Florent. part. II. §. 3. p. 22, &c.

into fluid glass. Iron by the addition of sulphur is melted by a moderate fire. Nitre fixed by the help of tartar, assists the fusion of other metals.

§. 769. Metals which flow before they are well impregnated with fire, have not conceived their greatest quantity of fire at melting, but when they are red hot and shine. For lead, from the degree of it's first fluidity, to it's splendour in the fire, has excited in iron 46 degrees more of rarefaction. But whether other metals, which melt only when red hot, are thus affected or otherwise, I have not yet exactly discovered. But I should conclude from other observations, that when they begin to flow they have not yet arrived at their greatest heat. Is not this the reason of it, because the fire first entering the largest pores, removes the parts sufficiently from one another, so that they no longer cohere, but are reduced to a state of fluidity; but it has not yet entered the narrower pores of the particles, nor saturated them with the whole quantity possible; which when it has entirely filled, the whole mass is red hot, and cannot admit of any more fire. But what must we say of iron, which when melted in a crucible, is found to be of a less volume than before when it was cold, and that this is the only metal which is dilated as it grows cold? Cold iron is condensed, grows rarer by the fire, and so much the more as it is more impregnated by the fire, till it is reduced to a fluid state; if then it be poured into moulds, and from a fluid state begins to be changed into a firm mass, it swells, and in it's inmost substance acquires small, copious, and empty cavities; becomes firm iron, though still very red, and proceeding to grow cold, is no longer inflated, but shrinks, and the colder it grows, the more it is condensed. No man living has made more ac-

curate trials upon iron, than Mr. *Reaumur*, that brightest ornament of *France*. But after metals are reduced to fluidity, and are saturated with the greatest quantity of fire, though they remain in the fire never so long, they receive no more, but partly becoming volatile they pass into air, and are partly turned into ashes, and these finally into glass.

§. 770. And so it is likewise with other bodies, as pitch, sulphur, &c. that action of fire, by which it makes the parts volatile, is called *evaporation*, or *exhalation*. This happens in the subtlest parts of bodies, which may chiefly be rarified by fire, may be rendered specifically lighter, may be more easily moved by it, and drive upwards. All which things while the parts undergo, they acquire an elastic force.

§. 771. After that the more subtle parts, chiefly those that are watery and oily, have been expelled from bodies by the action of fire, the grosser parts stay behind, being separated far from one another by the fire, which afterwards flying away, they scarcely touch one another, hardly attract, do not cohere, and are called *ashes* or *calx*.

§. 772. As soon as the fire is fled away from the aforementioned firm bodies, that is when they grow cold, the bodies are condensed, passing through successive degrees into a lesser extension.

§. 773. By how much the more bodies have been heated by the fire, so much the sooner they are condensed, if put in a place or medium that is less hot; the greatest quantity of the fire then flying away. But by how much they were less hot, by so much they are condensed more slowly.

§. 774. Such firm bodies as are soonest expanded by fire, when taken from the fire are soonest contracted, or grow cold. Because as the fire has

an

an easy entrance into them, so it easily goes out. On the contrary, they preserve the heat more tenaciously, which receive it with more reluctancy and difficulty.

§ 775. Whatever fluids have been examined, as air, common water, the waters of medicated plants, wine, vinegar, spirit of wine, the expressed oils of the same plants, isicles, acid and alkaline saline spirits, quicksilver, when shut up in phials with a wide belly ending in a long thin neck; being exposed to the fire are expanded, and ascend out of the belly into the neck: and ascend so much the higher, as they are exposed to a greater fire; but this within a certain limit. When taken from the fire and put into a colder place or medium, they are contracted, shrink, and from the neck descend again into the belly of the phial; and are condensed so much the more, the more they are deprived of fire.

§. 776. Therefore fire insinuates itself into all bodies that have been yet tried, whether firm or fluid. First it fills up the interstices of the parts, and repels the parts from one another, then it enters the pores of the parts, and perhaps also the pores of the particles, even to the least, by separating at last even the elements themselves. Wherefore the whole body swells, being most intimately penetrated by the fire. Because all the bodies upon the superficies of the earth, in winter and summer, are sometimes exposed more obliquely to the rays of the sun, and sometimes to the more dense and striking more directly, they will be expanded into a greater volume by successive degrees, the more we proceed from winter to summer. Besides, by how much the places of the earth are exposed to a greater quantity of rays, so much the more will the bodies be rarified which

are found there. And as this happens in the places which are near the equator, it is manifest, that bodies near the equator will swell more, than those that are in the colder polar regions. Therefore the pendulum of a clock, which is made of metal, will be shorter in the colder climates, than near the equator. Also because the sun rises daily, and warms the earth, which grows cold again when it sets, all bodies upon the earth's surface will be expanded in the day-time, and will be again contracted in the night-time. And therefore all bodies will be in a continual succession of contraction and dilatation. They will be dilated by the fire, which drives away the parts, and contracted by the attractive force, by which the parts perpetually approach towards a closer union, and by which the fire is expelled.

§. 777. Yet there are certain firm bodies, which are contracted when exposed to the fire, and not expanded. Such are all the woods of trees and of shrubs; also the parts of animals, as bones, membranes, and strings made of their intestines. These contractions are made, because the fire expels the subtile parts of these bodies, and flies away with them; whence the remaining solids, still approaching to a closer union, come nearer to one another, though they were removed by the fire. But they are now less separated by the fire, than before by their volatile particles, so that being deprived of these, they are diminished, and necessarily contracted.

§. 778. As firm bodies are unequally dilated by the same fire, both as to bulk and celerity, it will not be otherwise with fluids. In the experiments the rarefaction seemed to be swiftest and greatest in air, and always less in other fluids in this order.

Air,

Air, alcohol, petrol, oil of turpentine, rape-oil, distilled vinegar, water, salt-water, aqua fortis, oil of vitriol, spirit of nitre, quicksilver.

§. 779. The fluids aforementioned, and all others except air, by help of fire may be reduced to ebullition, and then they are as hot as they can be in the open air, and are in their greatest expansion.

The alcohol, from the degree of the greatest artificial cold, excited by the help of spirit of nitre, and now bubbling, is expanded $\frac{1}{8}$ part of it's whole volume. Water from the same cold to it's ebullition is expanded $\frac{1}{85}$ part of it's bulk. Mercury from the same degree of cold to it's ebullition swells to $\frac{4}{57}$ parts of it's magnitude.

§. 780. Because fluids are more expanded than fixed bodies, by an equal quantity of fire, they have been applied to detect the quantity of fire, which is concealed in all bodies whatever. The instruments appointed to this use are called *Thermometers* or *Thermoscopes*.

Because air is much rarified by a moderate fire, *Drebbelius* thus constructed an aerial Thermoscope. To a capacious sphere of glass A is joined a tube BE, and any vessel D contains a liquor. First a little air is expelled out of the sphere A, then into the tube of the open orifice E, the liquor ascends being pressed by the weight of the atmosphere, suppose as far as C. As soon as a greater quantity of fire enters the sphere A, it's air rarifies, and has no room to betake itself to, unless it somewhere expels the liquor from C towards E. Therefore the liquor descends more or less in the tube, according to the quantity of fire that enters and rarifies the air. This Thermoscope is very easily affected; but since the weight of the atmosphere is variable, by which the

the liquor is suspended in the tube, it cannot be long trusted. For if, by the increase of the weight of the air, the liquor should ascend in the tube beyond the mark C, and at the same time the air in the sphere A, being rarified by a greater quantity of fire, should depress the liquor as much, that being acted upon by each cause in opposite directions, it should still remain at C; the same degree of heat will still seem to have continued, which yet had increased. And we should not know that it had increased, unless we were assured by other tokens, that the weight of the air was changed. But when this is known, we should not yet know that the heat was increased, which involves the observation in great difficulty. For the fluid in the pipe will be as much moved by the change of the weight of the atmosphere, as by a different degree of heat. I need not mention any more inconveniencies of this instrument, which is now grown into general disuse.

Tab. 10.
Fig. 24.

§. 781. Into the place of this the *Florentine* Thermoscope has been substituted, so called because it was invented by the Philosophers, who composed the *Leopoldine* academy at *Florence*. Here also to the sphere A a small glass tube B C was annexed, at a time when the heavens enjoyed a temperate heat; it is filled with tinged spirit of wine as far as the middle D, then the upper part of the tube C is sealed hermetically. And so in this Thermometer the spirit does not lye under the weight of the atmosphere. A scale is added, divided at pleasure into equal parts, reckoning from D towards C, and from D towards B. The spirit in the sphere A being rarified by a greater quantity of fire, will ascend higher in the tube; and when the fire goes away, it descends out of the

the tube towards the sphere. Now though this Thermoscope is better than the former, yet it is liable to the following errors. First the scale which is affixed to it begins from no fixed and constant term, neither does it end in a fixed term, nor do the divisions shew any thing certain about the quantity of rarefaction. Secondly the air, which must be necessarily left in the upper part of the tube, being expanded by the approaching heat, resists the ascent of the liquor, and hence the liquor will ascend in the tube less than it ought to do. Thirdly, the higher the liquor ascends in the tube, so much the more it gravitates downwards upon the sphere, and is an hindrance to the ascent of the liquor. Fourthly, in process of time the spirit loses much of it's fluidity and elasticity, and being grown stale it does not so easily comply with the fire, by expanding itself, as when it is fresh. Fifthly, the glass itself becomes more capacious by heat, and is more contracted by cold; so that the rarefactions of the ascending liquor are perceived to be less, and the descents also to be less, than if the vessel were always to continue of the same capacity, which always should be in these experiments. Sixthly, it can be used only for measuring a small difference of heat; for spirit of wine boils sooner than any known fluid, so that the degrees of heat of boiling fluids cannot be discovered by it's means. Seventhly, by intense cold the spirit is converted into ice, as was observed by the ingenious Mr. *de Maupertuis* in *Lapland*; so that the cold of the atmosphere, and much less any more intense degree of cold, cannot be observed by this Thermoscope. Eighthly and lastly, hardly two or more Thermoscopes, that shall go alike, can be constructed after this manner. Partly because

cause two globes, which are in the same ratio to the capacities of the tubes, can hardly be procured; and partly because all spirit of wine has not the same facility of dilatation.

Tab. 10.
Fig. 25.

§. 782. These faults being known, it were better to make use of mercury than spirit of wine. For pure mercury has the same degree of dilatation, and always remains the same. Besides instead of a sphere, a cylinder may be annexed to the tube, which easily may be chose of such a magnitude, that it's capacity may have any determined proportion in respect of the tube; namely as 11124 to 670. By observing which, several Thermoscopes may be constructed to the same scale. And the cylinder may be made of glass of a moderate thickness, lest when the tube is sealed hermetically, the internal capacity may be diminished by the weight of the atmosphere, which before had been nicely adjusted in the air. To this inconvenience those Thermometers are subject, the concave belly of which, to increase the superficies, was made of a different figure, and of thin glass. Secondly, that the mercury may be dilated in the most equable manner, it must first be freed from all air; then let the more capacious cylinder be filled with it, and part of the tube, which above is left quite empty of all air. Because mercury will not boil without much fire, and very difficultly, it is proper for measuring the several degrees of heat of all bodies. And because it will not be frozen into ice by any degree of cold, it will serve also for measuring the degrees of cold. A fixed and constant scale may also be adjoined to it, beginning from unity, denoting that degree of cold, which in these climates is produced in winter, by ice mingled with sal ammoniac. The number 70 is put below the first,

first, when the greatest cold is observed, whether natural or artificial. The number 32 is put above the first, when water begins to freeze into ice. 212 is put, when it stands in boiling water. And 600 is there placed, when the mercury begins to boil. And thus it will be known how much the mercury is dilated, when it stands at any degree; because the capacity of the cylinder is given, in respect of that of the tube.

This Thermoscope will be without the faults 1, 2, 4, 6, 7, which we have taken notice of in that of *Florence*; but it will be liable to 3 and 5. And though 3 may be prevented, by placing the tube horizontally, the fifth defect has hitherto not been removed. Therefore by the degrees of ascent we cannot determine any thing certain about the true quantity of rarefaction; much less can we lay down for certain, that the real quantity of fire will be measured by such an instrument.

For first, the beginning of the scale is not placed, when the mercury was purged from all fire; since a much more intense degree of cold is now known.

Secondly, we cannot tell whether a rarefaction of a body being given, proceeding from a certain quantity of fire, that the rarefaction from a double quantity of fire will be as great again. In firm bodies this by no means obtains, because of the attractive power of the parts. And something like this may obtain in fluids.

Thirdly, if all fire does not move with equal rapidity, a good deal of fire that moves more slowly may enter the mercury, and rarify it a little; or but little fire that is much agitated may rarify it much. Therefore the expansions of the mercury observed in the tube will not exhibit the
measure

measure of the quantity of fire. And yet these Thermoscopes are the best and most perfect of all, which art has hitherto found out, and which we chiefly owe to the most ingenious *Fabrenbeyt*. How they may be constructed I have explained in short, in my commentaries annexed to the *Florentine* Essays. The most ingenious Mr. *Reaumur* has endeavoured to improve the *Florentine* Thermoscope ^a, and has adapted to it a fixed scale, with good success. Also he cleanses the spirit of wine of it's air, he expels it out of the phial and tube by means of fire, so that this Thermoscope is brought to the utmost perfection it is capable of. But it must still yield to the mercurial Thermoscope in point of perfection, because it cannot serve for measuring all degrees of cold, not even that which is natural, nor can it indicate the heat of any boiling fluid, because in a few years the spirit of wine grows foul, and loses a great part of it's activity.

§. 783. As often as a greater heat of bodies is to be examined, than boiling mercury can attain to, our Pyrometer may be applied, which accurately measures the expansions of the most ardent bodies.

§. 784. The mercurial Thermoscope, constructed according to the foregoing scale, most evidently shews, that various liquors will require a different quantity of fire, to make them boil. This will not be in proportion to the density of the bodies, since light oils, if they are hot, require much fire, alcohol of wine will boil when the mercury stands at 176 degrees, quicksilver in boiling water ascends to 212 degrees, in boiling spirit of nitre it ascends to 242 degrees, in boiling lixivium of tartar to 240 degrees, in boiling oil of

^a L'Histoire de l'Acad. Royal. Aout. 1730.

vitriol to 546 degrees, and quicksilver itself boils at 600 degrees; nor will linseed oil boil sooner.

§. 785. It has been observed by the assistance of Thermoscopes, that mercury or spirit of wine, (if the *Florentine* machine be used) being suddenly immersed in a much colder liquor, will first ascend in the tube, and then descend. But on the contrary, if they are immersed in a much hotter liquor, the mercury or spirit will first descend in the tube, and afterwards ascend. This happens because the glass of the Thermoscope is sooner affected by the cold or the heat, than the mercury or spirit which is contained in it. The glass is contracted by the cold, and therefore the mercury ascends being expelled out of the belly. The capacity of the glass is increased by the heat that dilates it, and therefore the mercury descends in the enlarged belly of the Thermoscope, and so long till the glass being now penetrated by the fire, and still creeping forwards, the fluid itself begins to be rarified. The ingenious *Bulfinger* has confirmed this by other experiments^a. Wherefore all the vicissitudes of ascent and descent, which the mercury shews in the Thermoscope, are only it's rarefactions, which are greater or lesser than those, to which the glass is exposed by the same fire. Tab. 10.
Fig. 26.

§. 786. Fire which thus copiously insinuates itself into bodies, and adheres to them, is found to increase their weight, and therefore like all other bodies is itself endued with gravity.

This must be proved by a few experiments, such as have been described in great plenty by *du Clos*, *Boyle*, *Homburg*, and others. It is well known that 100 pounds of lead, calcined in a vehement

^a Comm. Acad. Petropol. Vol. III. p. 242.

fire, have yielded 110 pounds of minium. *Hellote* has reduced 4 pounds of zinck into a calx, and has obtained 3 pounds and 14 ounces of a very white beautiful calx, besides 2 ounces and 2 drachms of a more gross and less white calx, and 1 ounce of earth. So that every pound gave an increment of weight, of $2\frac{1}{2}$ drachms, though at the same time much of the metal went off in smoke*. But we may better trust to such experiments as are made with vessels well closed. Shavings of pewter to the quantity of 2 ounces were included in a glass retort, which was afterwards sealed up, and kept for an hour and half in the flame of burning sulphur; it was converted for the most part into a calx, which being afterwards weighed, was found to have received an additional weight of $4\frac{1}{2}$ grains.

An ounce of filings of copper was put into a crucible, and covered with a tile, and then exposed to the fire for the space of 3 hours. The metal being cold, and now black, acquired the weight of 49 grains.

An ounce of shavings of pewter was put into a glass retort, which was then sealed hermetically, and exposed to the flame of spirit of wine for two hours. When it was cold and weighed, it was found to have acquired an increase of weight of $4\frac{1}{2}$ grains.

Fire being collected in three different kinds of combustible matter, and being stirred, had the same effect by affording an increase of weight. But hence a suspicion might arise, whether some of the more subtil parts of the earthly matter, along with the fire, might not pass through the glass vessels and the crucible into the metals that were examined, which might increase their weight, and not the fire. This doubt may be cleared up,

* L'Hist. de l'Acad. Royal. An. 1735.

if the beams of the sun, which constitute the purest fire, should perform the same effect.

Du Clos took a pound of regulus of antimony, reduced to the finest powder, and putting it into a well-glazed earthen vessel, he exposed it to the focus of a burning speculum. A white and thick smoke proceeded from the antimony, and in an hour's time the powder was reduced as it were to ashes, and was increased by a tenth part of it's former weight.

These experiments were made upon various minerals, and gave a like increase of weight, as may be seen in *du Hamel*^a. *Homberg* found the same thing in antimony, by means of a burning-glass, which is confirmed also by *Lemmerly*^a. Lead being melted in the focus of a very great burning-glass, and then calcined, and changed into glass, though it had emitted much smoke, yet it was increased in it's weight, as *Zumbach* observed at *Cassel*. Therefore fire, whether terrestrial or pure celestial, increases the weight of bodies, inheres in them, and therefore has weight itself.

§. 787. In all the experiments, which shew that weight was added to bodies by means of fire, the bodies were exposed to a constant and copious fire, were deprived of their elasticity and cohesion, were reduced to a calx in which much fire was detained and included, which had a notable weight of it's own. Whatever has been attempted by some, in opposition to this gravity, is of but little consideration. For it is not to be wondered at, that a small quantity of fire, collected into a body, should have no sensible weight; so that a mass of iron, being weighed when cold, then heated

^a Hist. Acad. Reg. lib. 1. sect. 2. c. 1.

^b L'Hist. de l'Acad. Roy. An. 1709, & in *Chemin*, cap. 5.

and weighed again, seems to have continued of the same weight. But if we consider the mass was weighed in the air, that it is of a lesser volume cold than hot, and therefore being inflated and hot, that it ought to indicate less weight in the fluid air, and though it has the same, the fire in it is of so much weight as the body had lost of it's weight, because of it's volume being increased. Wherefore by this experiment nothing can be proved against the weight of fire, but it rather confirms it. But the heated iron remains of the same weight, because it is so little rarified; whereas other metals, which swell to a much greater bulk, being heated become lighter. For 4 pounds of melted lead were lighter by 4 grains, and 4 pounds of melted pewter were lighter by only 2 grains. For lead before it runs is expanded into a much greater volume than pewter, and therefore is more sustained by the air. And these metals are rarified much more than iron by the same fire. But as long as bodies continue firm masses, or are restored to them again, they again expel fire out of them by their attractive force; which does not obtain after calcination. Much less does the flame of burning bodies, which ascends and does not descend, overthrow the weight of fire; because this, together with the particles of the bodies which are much rarified, compose a mass specifically lighter than that air, through which it ascends. Therefore in finer air the flame always ascends less and less, till in air that is much rarified it does not ascend at all. Another difficulty has been moved, that bodies, which have been calcined by a burning-glass, acquire a greater increase of weight in open vessels, than in those which are closed; therefore they say, that some particles have accrued from the air, which have increased

increased the weight. But if in closed vessels the weight of the calcined bodies has increased, this could not be owing to the air, the access of which was hindered. The greater or less increment depends upon a longer or shorter, a stronger or lighter calcination, and therefore we must conclude, that fire is endued with gravity.

Another scruple remains, that the weight of bodies, reduced to a calx by means of the rays of the sun, is much increased, whereas light is a very rare and subtil thing, and therefore in the time in which the calcination is performed, can only communicate an infinitely small gravity to bodies, and not so great as we observe it to be. But who can tell the weight of an intire ray of the sun? Who can determine the quantity of rays falling upon a body, reflected by it, or inherent in it? If a ray from the sun, extended as far as the earth, had the gravity of $\frac{1}{100000000}$ part of a grain; then 100000000 rays would have the weight of one grain, all which entring a body, which is reduced to a calx, in the space of 7 or 8 minutes, will give an increment of weight equal to one grain; and therefore 60 more such will add to the body the weight of a drachm: so that this scruple is likewise but of small moment.

§. 788. Now from all that has hitherto been delivered, concerning fire, it plainly follows; first, that fire is a body, because it occupies space, and extends itself from a heated body to all the bodies or spaces round it. Therefore it has motion, because it expands itself. It has solidity, as is shewn by it's repercussion by burning-glasses. It has also gravity. Some think that fire is penetrable, but not solid; because if a ray of the sun falls perpendicularly upon a speculum, it returns again the same way, which could not be if it did

not penetrate itself. But the incident and reflected rays cannot run near one another, for there is no reason why the incident ray should be deflected from it's course. A subtle argument this! But I desire to know, whether it appears by any experiment, that a single ray of light, reflected by a speculum, returns through itself? It must not be replied, that a sensible ray is so moved; for such an one consists of innumerable small diverging rays, so that any one of them may easily return in an adjacent line, without any mutual penetration. Secondly, fire will consist of parts extremely subtile, since it penetrates into the pores of all bodies whatsoever, as well compact as fluid. Thirdly, it's parts will be most solid, because they are the least, and therefore not much porous; and perhaps they are elastic. Fourthly, they must have a most smooth surface, for this is a consequence from their faculty of penetrating into all bodies, even their most intimate recesses; which could not be if the particles of fire were rough, shaggy, or hooked. The very great fluidity of fire shews the superficies of the parts to be smooth and slippery, which obtains only among corpuscles of a spheroidical figure. Fifthly, fire is also endued with extreme mobility, since it moves the parts of other bodies with the greatest rapidity, as easily appears by the focus of burning-glasses. It can adhere to bodies, for it increases their weight, and flies away with those which it has made volatile. Seventhly, it can be reduced to rest, at least to a less rapidity than it had before; for it adheres to the calx of metals, and of other bodies which do not grow hot by the Thermometer. These calxes imbibe so much the more fire, as they have continued longer in it; as appears if two equal lumps of stony calx be macerated in water, of
which

which one lump has endured the fire longer than the other. By this calx the water will grow much hotter. And the same thing happens in alkaline salt. A large quantity of fire, when pent up within the parts of bodies, very often shines, as may be seen in the *Helvetian* androdamas, in the *Bononian* stone, and almost in all other stones, whether calcined, or first dissolved in acid spirits, and afterwards calcined; as also in boles, earths, the bones of animals, the ashes of plants. For all these things, being something illuminated by the sun, and then carried into an obscure place, will shine and retain the light for some time; nay, if they lose it, being again exposed to the sun, they will recover it again. The *Bononian* stone, being preserved in cotton, keeps its shining virtue above five years. The calcined belemnites and the topaz do the same. It has been tried, whether the light of the *Bononian* stone were solar light, or light that has entered into it, and then agitated with new motion by light. But light separated into colours by the prism, and projected upon this stone, shews it to be light that had been before imbibed, and now agitated afresh by the sun's light. However many other bodies imbibe the light of the sun, and keep it for some time, as diamonds, sapphires, amethysts, and other precious stones. But there is a wonderful variety of bodies, so that trials do not always answer expectation. *Du Faye*, who has notably promoted this inquiry, placed diamonds of several colours in the sun for the space of 22 minutes; then in the dark he found the yellow ones to shine much, but the others not. At another time the yellow and the blue ones shined a good while. There are shining emeralds, as also crystals, and lapis lazuli. They equally imbibe light, whether

The ELEMENTS of

placed in the open air, or under glasses, under water, or milk, but not under ink. Bodies endued with the property of imbibing light may lose the same by frequent ignitions, as is observed in crystals, the phosphorous stone of *Bern*, and emeralds. There are others which acquire that faculty by ignition, as the *Bononian* stone, the belemnites, gypse, the phosphorus of *Balduin*^a.

§. 789. Fire is susceptible of very different degrees of velocity, continually decreasing before it passes from that most rapid motion, which it enjoyed before, to a lesser and lesser degree, and finally almost to a state of rest. Therefore there may be sometimes much fire in a body with but little motion, or with but small effects of it; and sometimes but little fire with a great effect. Perhaps phosphori prepared from the parts of animals are of that nature, that whereas they are cold under water, and not shining, but only shine out of water, they may possibly contain a great deal of fire, but which is chiefly at rest. Therefore as soon as their fire begins to move, it immediately shews the great abundance of it, both by it's easy inflammation, and also by it's heat. Also minium, heated *in vacuo*, proves the same by it's vehement expansion and burning.

§. 790. Fire inherent in bodies is retained by some circumambient bodies, and by others is extracted as it were, either sooner or later.

For metals, stones, pebbles, woods, fluids, shut up in vessels and made hot, and afterward wrapped up in wool, flocks, feathers, skins of animals, hair, will keep hot for a long time. On the other hand, if water or other liquors is poured upon them, or if they are committed to the open air, they will soon grow cold.

^a L'Hist. de l'Acad. Royal. An. 1730, 34, 35.

Hot water sooner loses it's fire in *Boyle's* vacuum, than in the open air. Rotten and shining wood, surrounded by air, retains its fire for some days, of which it will be soon bereaved if put into *Boyle's* vacuum. This wood, when once deprived of it's fire, does not recover it again by being restored to the air. Lampyris shines in the air, in the vacuum ceases to shine, and admitting the air it shines again. Yet iron keeps its fire longer *in vacuo* than in the air; and perhaps many other bodies are subject to the like irregularities.

§. 791. As often as a heated body is laid upon another that is less heated, it communicates it's fire to it. And so much as it communicates, so much it loses: and it continues to communicate till both are equally hot.

§. 792. After this manner all firm bodies operate upon firm and fluid bodies, and fluids upon fluid and firm bodies, without any difference hitherto known.

§. 793. Wherefore fire passes out of bodies by diffusing itself all round about, till it remains in equal quantity in all near and ambient bodies. Therefore if in any ample space there should be found many bodies together, whether firm or fluid; as iron, lead, marble, flocks, wool, feathers, cotton, wood, cork, wine, water, oil of vitriol, quicksilver, or any other whatever; and if these were contiguous to one another for some hours, and the place was warmed neither by the sun, nor by fire lighted in it, nor by the heat of men; all these bodies, examined by means of a very tender Thermometer, would appear to be equally ignited, or equally hot. Yea, the Thermoscope, or the bodies with it, included in the *Boylean* or *Torricellian* vacuum, would shew the

same quantity of fire. For the fire will be equally distributed through all, so that in a cubic foot of gold, and air, and feathers, there would be an equal quantity of fire. Does this depend on the elastic nature of fire?

§. 794. Therefore a Thermoscope suspended by a long thread, and made to vibrate in the air, can shew no difference of heat or cold. Even wind, blowing upon the Thermoscope by a pair of bellows, will not cause any change in it. But if the Thermometer be moistened by water, and then the wind blows upon it, a notable change will follow, cold immediately arising. Sailors know this, when among their sails they hang up vessels rolled up in moist clothes, that they may be cooled by the wind. These experiments require no small care, nor can they be performed before many spectators, because the place would soon grow warm unequally, by means of their bodies, and some bodies receive fire into themselves sooner than others.

§. 795. Therefore do bodies at rest, when freely left to themselves, attract fire alike, or do they do it with unequal force? If it were so, some bodies would remain hotter than others. Yet light, as we learn from *Newton's* experiments, is attracted more strongly by sulphureous bodies than by others. Or is this difference of attraction so small, that the rarefaction of bodies cannot shew it, by the assistance of our Thermoscopes, though the refraction can?

§. 796. It may also be understood by the equal distribution of fire, why fire from a burning coal, from a ball of metal, or of stone made hot, passes as well upwards as downwards, and sideways, and every way; as the Thermoscopes prove.

§. 797.

§. 797. But fire also will be equably dispersed through all the parts of the ignited body. But because a body applied to another touches it only in the superficies, to which the fire is communicated first; the other body growing hot will keep the fire in the centre for a long time.

§. 798. I took notice in §. 793, that in any place the fire would equably diffuse itself through the whole space, and the bodies placed in it; therefore if a Thermoscope be suspended in the open air, so that it may not be illuminated by the sun; it will show the degrees of the fire near the earth, and at the height of 10, 20, 30, or 40 feet. But in houses which consist of several floors lying over one another, this equability of fire will not be observed in all, either by day or night. But at noon the highest dining-room may be observed, which will be also the hottest. The next lower story will not be so hot, and the lowest will be least hot of all. At midnight the lowest are found to be the hottest, those nearest the roof are the coolest, and the middle ones of a middle degree of heat. This is because the roof being most exposed to the heat of the sun, in the day-time is most heated by it. In the morning the fire gradually penetrates through the cielings and floors, even to the lowest, to which it arrives though late. At night the external air, being very soon cool, fans the roof, which therefore soon cools, and the fire gently passes upwards from the lower chambers, through the cielings and roofs.

§. 799. If two bodies of the same matter, that are like and equal to one another, are made equally hot, and one of these be laid upon a hard and dense body, the other upon a softer and rarer body; then that which is laid upon the denser body will sooner lose it's fire, and a greater quantity of it, than

than that which is laid upon the rarer body. And besides the hard and dense body will seem to have received less fire than the other rare body.

§. 800. This also obtains in fluids. For let air, water, and quicksilver, being equally hot, be contained in three equal vessels; and in these fluids let there be immersed three equal pieces of iron which are equally heated. That will retain it's heat longest which is put in air, that sooner loses it's fire which is immersed in water, and that soonest of all grows cold which is immersed in the quicksilver.

For fire entering into one body out of another, must move it's parts, which as they are more in multitude and more cohering in the denser and harder, they will be moved with more difficulty, and consume more of the strength of the fire. Therefore the heated body will seem sooner to have lost it's fire, and that which receives the fire will seem to have received less of it.

§. 801. Hence we know the reason, why if we lay our fingers on metal, stone, or wool, which are equally hot, the metal will seem to be colder than the wool. For the finger touches more parts of the metal than of the wool, and cannot move them so suddenly with it's fire, being harder and less susceptible of motion, as the moveable, thin, and rare particles of the wool. Secondly we know also, why our fingers are sooner cooled by metals and other solid bodies, than by wool.

§. 802. Wind blowing upon the Thermoscope does not heat it less than the calm air, by §. 794. Yet wind is used to cool a human body much more than the calm air, and blowing upon it when hot brings diseases, not arising from itself, but from the stagnating air. This comes to pass
because

because the human body is naturally hotter than the ambient air. Therefore it heats the air, in which being at rest we are placed as it were in an atmosphere, being of the same or of something less heat than our own; and therefore we feel the air to be hardly or not at all cool. But the wind blowing upon us, the whole warm atmosphere is drove away from the body, and a new air immediately encompasses it, not so hot as the body, by which the body must necessarily and quickly grow cool. And hence also it may be understood, why our breath breathed upon the back of our hand with our mouth open will seem hot; but blown upon it with our mouth contracted will be cold.

§. 803. Bodies generally retain fire so much the longer, the more difficult it is to make them receive it. The heavier and harder bodies are, with so much the more difficulty they are heated; as iron, copper, stones. But those also preserve fire very long. But chalk is most difficult to be made hot, and loses its heat very soon. The lighter bodies are, so much the sooner they lose their fire. Hence air loses heat sooner than alcohol, this sooner than water, and this sooner than quicksilver.

§. 804. The greater bodies are that are of the same matter and figure, so much the longer they preserve their fire, being equally heated, and placed in the same medium. Let a small wire and a thick iron rod be made red hot in the fire, and at the same time be suspended in the air; the wire will sooner be cooled than the rod. For bodies receive fire in proportion to their surfaces, and retain it in proportion to their magnitudes. Let two like cylinders, prisms, cubes, or spheres be supposed; their superficies will be as the squares

squares of their diameters, but their magnitudes will be as the cubes of the same diameters. Let the sphere A have it's diameter of 1 foot, and let the diameter of the sphere B be 10 feet. Their superficies will be as 1 to 100, and their solidities as 1 to 1000. So that the sphere B will retain it's fire 10 times as long as A. If our earth were a globe of iron, and were heated red hot, and then were left to it's self, it would be hot for the space of 50,000 years, before it would lose all it's fire.

§. 805. If bodies that are firm, hard, and dry, were to move swiftly, and to rub violently against each other, they would first begin to be warm, and afterwards to grow hot. The attrition being continued and increased, the heat would also increase, till at last the bodies would grow hot, or would be lighted up into a flame, if they were combustible bodies.

Woods, and chiefly those that are hard, (for every sort of wood could not supply proper matter,) are set on fire by attrition only ^a, hence the burning of woods, by the boughs of trees agitated by the winds, and rubbing against one another ^b. A blunt steel auger, violently boring hard wood, will grow very hot. *Robault* tells us, that as he drew his saw to and again through a piece of hard wood, it grew hot, and he perceived a smell as it were of burning wood. Iron laid upon an anvil, and struck with hammers swiftly and often, becomes very hot ^c. Sugar beaten in a mortar manifestly shines. A rope wound about a tree, and swiftly drawn to and

^a Aristoteles lib. 3. de Cœlo. Senec. l. 2. cap. 22. q. n.

^b Lucret lib. 1.

^c Du Hamel. in Hist. Acad. Reg. l. 2. §. 2. c. 2. Hooke in Exp. a Derham. edit. p. 287.

fro for a good while together, and with strong compression, will be hot and burn. An agate rubbed against an agate emits flame. A tube or ball of glass, after a strong friction with the hand, or with a cloth, or with paper, will grow hot, and manifestly shine. An amalgama of mercury shines, when rubbed upon a glass speculum. Gold, silver, copper, diamonds, and any precious gems will shine when rubbed against glass ^a. Tutty bruised into parts with a hammer in the dark, disperses a bright and great light like a phosphorus ^b. Mr. *Reaumur* mixed two parts of iron with one part of antimony, and melted it. This mass when filed with a rough file, exhibited a phosphorous powder, burning the paper ^c. A rod of iron, with which we stir antimony when it is reduced to a calx, becomes phosphoreous by striking ^d. Linen, silk, hard paper, when violently drawn between the fingers, is hot and shines ^e. Aurum fulminans, and crocus martis antimonialis, are inflamed when vehemently pounded. These phænomena shew themselves at any time, or in any place, even *in vacuo*, as *Boyle* ^f and *Hauksbee* ^g have shewn, by making a multitude of experiments *in vacuo*; by the vehement rubbing of a diamond, gum lake, sealing-wax, glass, amber, an oyster, wool, steel, flint. Steel striking a flint in the open air discovers very vivid sparks of fire, which being collected exhibit certain melted globes of metal changed into glass. But *in vacuo* these sparkles do not shine, yet however globes are produced like the former. Fire therefore is present every where, and in

^a L'Hist. de l'Acad. Roy. An. 1707. ^b commercium
Litt. Norimb. An. 1735. ^c L'Hist de l'Acad. Royal. An.
1736. ^d Idem. Ibid. ^e Philos. Transf. No. 366.

^f In Continuat. 1. Exp. Physf. ^g In Exp. Physf. Mechan.

every body, and that which before was almost at rest, or but little moved, by rubbing being again swiftly agitated from such parts, as by a vibratory motion tremble very briskly, then shews it's presence and efficacy.

§. 806. And because elastick bodies very easily tremble, and continue their trembling motion for a long time, elastick bodies by friction are fittest for collecting fire. Hence hardned steel striking against flint excites a greater quantity of fire than soft iron. For soft bodies have hardly any resistance, they do not tremble, or scarcely produce fire by being rubbed. Hence the bodies of animals, which consist of vessels which are very elastick, through which an elastick blood moves swiftly, so easily grow hot and collect fire. Whereas those animals, which are endued with lax bodies and watry blood hardly moving at all, are so sensibly cold. But do bodies grow hot by rubbing, by means of that fire only, which they contained before they were rubbed? Or do they receive an addition of fire from the ambient space, which is as it were attracted by the friction? This seems to be the case, because fire passes so easily from one body into another. As also because the denser a body is, so much the longer it retains fire, and the rarer it is, so much the sooner it loses it. Those bodies that burn, do it not with their own fire alone, but also with that which they receive from elsewhere.

§. 807. If among the bodies rubbed by friction, §. 805. any kind of liquor is poured, as water, oil, tallow, or fat of any kind, heat will hardly be produced, at least such as is not to be compared with the former. Hence it is that the axis of all wheels, whether of carriages or machines, are anointed with grease. For these fluids
fill

fill up and remove the asperities of the surfaces. And because being daubed upon the superficies, they hinder their mutual contact, and lubricate the motion of the bodies upon one another; hence but small trembling is excited in the parts, that scarcely excites the latent fire.

§. 808. If bodies of the same matter are like and equal to one another, and are painted or tinged with these colours, white, red, yellow, green, blue, purple; or if they are black, and alike exposed to the shining sun: then those that are white will be hot least and slowest, those that are coloured will be more and sooner hot, the heat increasing according to the order of the colours abovementioned, so that the black ones will be most and soonest hot. This appears in all kinds of cloth, which when wet and black will dry much sooner than white. Black walls in gardens are much hotter than white ones. Black earths are much hotter than white and bright sands. In the focus of a burning glass, whether refracting or reflecting, black bodies are much sooner set on fire than white ones. Sparkles struck from flint and steel soon communicate fire to black and burnt tinder, but not to white lint or rags. A black coal of wood, or charcoal, may be easily set on fire, when the same while it was wood could not be burnt but by a great fire.

§. 809. Black bodies are thus easily made hot, because blackness consists of very minute parts, which are most easily put into motion. Then besides, the fire that falls upon them suffers very many refractions, by which it is entangled and retained among the parts, and very little reflected from thence. Now a dark blue colour nearly approaches to a black, and therefore absorbs and keeps much fire, reflecting something more light
I back

every body, and that which before was almost at rest, or but little moved, by rubbing being again swiftly agitated from such parts, as by a vibratory motion tremble very briskly, then shews it's presence and efficacy.

§. 806. And because elastick bodies very easily tremble, and continue their trembling motion for a long time, elastick bodies by friction are fittest for collecting fire. Hence hardned steel striking against flint excites a greater quantity of fire than soft iron. For soft bodies have hardly any resistance, they do not tremble, or scarcely produce fire by being rubbed. Hence the bodies of animals, which consist of vessels which are very elastick, through which an elastick blood moves swiftly, so easily grow hot and collect fire. Whereas those animals, which are endued with lax bodies and watry blood hardly moving at all, are so sensibly cold. But do bodies grow hot by rubbing, by means of that fire only, which they contained before they were rubbed? Or do they receive an addition of fire from the ambient space, which is as it were attracted by the friction? This seems to be the case, because fire passes so easily from one body into another. As also because the denser a body is, so much the longer it retains fire, and the rarer it is, so much the sooner it loses it. Those bodies that burn, do it not with their own fire alone, but also with that which they receive from elsewhere.

§. 807. If among the bodies rubbed by friction, §. 805. any kind of liquor is poured, as water, oil, tallow, or fat of any kind, heat will hardly be produced, at least such as is not to be compared with the former. Hence it is that the axis of all wheels, whether of carriages or machines, are anointed with grease. For these fluids

fill

fill up and remove the asperities of the surfaces. And because being daubed upon the superficies, they hinder their mutual contact, and lubricate the motion of the bodies upon one another; hence but small trembling is excited in the parts, that scarcely excites the latent fire.

§. 808. If bodies of the same matter are like and equal to one another, and are painted or tinged with these colours, white, red, yellow, green, blue, purple; or if they are black, and alike exposed to the shining sun: then those that are white will be hot least and slowest, those that are coloured will be more and sooner hot, the heat increasing according to the order of the colours abovementioned, so that the black ones will be most and soonest hot. This appears in all kinds of cloth, which when wet and black will dry much sooner than white. Black walls in gardens are much hotter than white ones. Black earths are much hotter than white and bright sands. In the focus of a burning glass, whether refracting or reflecting, black bodies are much sooner set on fire than white ones. Sparkles struck from flint and steel soon communicate fire to black and burnt tinder, but not to white lint or rags. A black coal of wood, or charcoal, may be easily set on fire, when the same while it was wood could not be burnt but by a great fire.

§. 809. Black bodies are thus easily made hot, because blackness consists of very minute parts, which are most easily put into motion. Then besides, the fire that falls upon them suffers very many refractions, by which it is entangled and retained among the parts, and very little reflected from thence. Now a dark blue colour nearly approaches to a black, and therefore absorbs and keeps much fire, reflecting something more light
I back

The ELEMENTS of

back again to that which falls upon it. And because bodies send back so much the more light, or fire, as they are indued with a bright colour; hence white bodies least of all grow hot, red bodies something more, orange more still, then yellow, green, blue, purple, violet-colour, and black most of all.

§. 810. Black bodies, exposed to the light, hardly reflect any of it back, but absorb it all into themselves. Hence it is that they grow hot so much and so soon. This is proved by the burning-glass, which when covered with the black smoke of a lamp, and then exposed to the sun, sends no light to the focus, nor rarifies the Thermoscope placed in it. But the speculum itself soon grows hot. Mr. Boyle made a large burning speculum of black marble, but though he opposed it for a long space of time to the scorching sun, he could never set on fire a piece of wood, which he placed in the focus. But white bodies return back almost all the light of the sun; and therefore burning specula are made with white metals with most success. White earths hardly grow hot by the sun, but they heat the air very much, into which they return the light. This the island *Ormus* informs us, which has very white mountains; these reflect all the light that falls upon them, almost inflaming the circumambient air.

§. 811. If the rays of the sun fall upon a concave, spherical, and burning speculum, they will be reflected back, and form a cone, whose basis is the superficies of the speculum, and whose vertex is the focus, which will be distant more or less from the superficies, according to the different magnitude and curvature of that sphere, of which the speculum is a portion. This focus concentrates all

all the rays and all the fire that falls upon the speculum; this focus vanishes in a moment, as soon as the speculum is covered, or turned away, or a cloud obscures the sun.

§. 812. Since therefore so great a quantity of pure fire collected together is so soon dissipated, and leaves no footsteps behind it, it appears that fire cannot subsist without something to support it, and upon which it may feed. Therefore the sun and fixed stars cannot consist of pure fire, for then they would vanish in a moment; but these luminaries must be very large, solid, and permanent bodies, that retain and feed fire, like the fire-stones upon our earth, and other stones mixed with combustible matter, which when once made intensely hot, will continue so for a long time. Also the spots in the sun, and the changes among the fixed stars in respect of brightness, directly prove the same thing.

§. 813. Burning specula that are cold reflect more rays of the sun than when they are hot, as we may gather from the effects produced in the focus. And therefore for the same reason they burn more vehemently in winter than in summer. For hot metals have larger pores than cold, and fire more easily penetrates into their enlarged pores. Besides the rarified parts of hot metals are less elastic, and therefore not so fit for reflecting the rays as when cold. And in hot weather very many exhalations arise from the ground, which fill the atmosphere, and something hinder the passage of the sun's light.

§. 814. The effects of burning-glasses are very surprising, especially of large ones, which collect many rays of the sun into their foci. For immediately in the focus any metal is melted, or semi-metal, and then is calcined, and afterwards

converted into glass. Gold itself is turned into smoke, and into blue glass, which cannot be done by any terrestrial fire, except zinc be mixed with it. All stones whatever are presently vitrified, and combustible matter is set on fire in the twinkling of an eye. But here I shall add some particulars, which have been found out by Mr. *Villet*'s burning-glass. Clays, sand, marble, jaspire, porphyrites, stones made use of for iron furnaces, crucibles, flints, bones of animals, pumice-stone, common bricks, blood-stone, *Vesuntine* chalk, gypse, plumbago, or clinkers of a smith's fire, when put in the focus, all of them melt and are changed into glass; and that how soon! according to the observation of that expert philosopher Dr. *Desaguliers*, a red piece of an ancient *Roman* patera began to melt within 3 seconds, and when melted was resolved into drops in 100 seconds. A piece of *Pompey's Alexandrine* column was converted into glass after 50 seconds. A copper ore, which seemed to have no metal in it, was changed into glass within 8 seconds. A human calculus calcined in two seconds was turned into liquid glass, which dropped within a minute. Asbestos, which is not combustible in a terrestrial fire, by *Tschirnbusse* was turned into glass of a yellowish colour.

§. 815. In the focus so great are the effects; but within the focus, where the fire is four times rarer, though in as great a quantity, a man's hand feels no more heat than what is tolerable. Is it therefore, because fire meeting with fire increases it's action in the highest degree, and not according to it's quantity? For this seems to be the case, though how this is performed we cannot apprehend, from any analogy of the operations observed in bodies. The rays of the sun collected into a larger focus, by means of a large burning-glass,

glafs, do not produce any great effect; but when by a fecond glafs they are collected into a fmaller focus, they operate much more violently, although fome of them are reflected by the glafs. Experiments made with the pyrometer fhew the fame thing. Now from the fame caufe a great heat will defcend into vallies, much exceeding that upon mountains, as *Nettleton* has obferved in *Great Britain*^a, and afterwards the ingenious *Galeatius*^b, upon the top of the very high mountain *Cimon*, which is one of the *Alpes*. For the rays being turned back by the fides of the mountains into the vallies, meet laterally the rays that are directly fent hither, and then reflected; whence muft arife a very great heat, greater than could proceed from the quantity alone. Becaufe the more folid bodies are more capable of receiving fire than the rarer, the denfe air in the vallies may be hotter than that which is rarer, at the tops of mountains.

§. 816. If the rays of the fun are collected into a focus, after they have paffed through a great burning-glafs of four feet diameter, they produce thefe effects; they fet fire to any combuftibles, and melt metals, but do not change them into glafs: fo that the action of thefe rays is much weaker, than of thofe that conftitute the focus of a fpeculum of the fame magnitude.

§. 817. But when the focus is contracted by means of a fecond lens, the force of the rays increafes; for in this contracted focus combuftible bodies are burnt, though ever fo wet, nay in the very middle of water; and the inward heart of the wood plunged in water, is confumed fooner than the outward bark, which is prefently extin-

^a Philof. Tranfact. No. 388. ^b Comm. Bonon. p. 104.

guished in the water. All metals laid upon a coal or earth of porcelane, are turned into glass. Stones are also melted and vitrified. Gems lose their colour, and are reduced into powder. All kind of vegetables are first turned into ashes, and afterwards into glass. Salts pass into spirits, such as no terrestrial and artificial fire can procure. All which is manifest from the experiments of *Tschirnbusse*, *Homburg*, *Geoffroy*, and chiefly of *Hartsoeker*, which I have also made, along with this famous philosopher.

§. 818. From these experiments it appears, that there are no terrestrial bodies that are absolutely fixed; for whatever is exposed to the focus of a burning-glass or speculum, becomes volatile. But the chemists call that a *fixed body*, which resists the action of fire and air, as not to be attenuated by them, or carried upwards, but always remaining in the same condition. And that is called *volatile*, whose parts are carried upwards by the fire or air, the grosser parts remaining behind. But in the focus there seems to be no change communicated to the air, perhaps because it does not resist the fire, but is immediately driven out of its place. For there can be no action where there is no reaction or resistance.

§. 819. The light of the moon, or of the planets, being collected together by means of the largest speculum or burning-glass, and condensed in the focus, shews no tokens in the finest Thermoscope, of the fluids being ever so little rarified or condensed. So that no sensible heat or cold, by any art hitherto known, is found in the focus of the lunar rays; as *Hooke*, *de la Hire*, *Villet*, *Tschirnbusse*, have proved by experiments made for this purpose. This sufficiently overthrows the opinion of *Paracelsus*, *Helmont*, and others, who
have

have imagined that the rays of the moon are cold and humid.

§. 820. This inefficacy of the focus is owing to the great rarity of the lunar light, and not because the light is without it's power of warming. For this light is darted from the sun to the moon, and from this again it is reflected to the earth. According to some experiments of *Bonquerius*^a, the density of the light of the full moon would be to that of the sun, as 1 is to 300000. But the burning-glass of *Paris*, made use of by *M. de la Hire*, condenses the rays only 306 times; so that the light of the moon, condensed by the speculum, was almost a thousand times rarer than the light of the sun shining upon the earth. Hence it is no wonder, that the Thermoscope in the focus of the moon's light should not be at all affected.

§. 821. If therefore the moon's light makes no alteration in a Thermoscope so easily moved; what ought we to think of that influence of the moon, or of the planets, which by the astrologers is fancied to be the cause of many terrestrial effects? Nothing surely can be more vain than all their doctrine.

§. 822. Furthermore, fire is collected in bodies, which when committed to the open air begin to rot, or to ferment; as appears in the putrifying bodies of animals, as also in moist hay heaped up together, and in fluids, and thin pastes made of meal. Fire is also collected, as often as two bodies of a certain texture, fluids with fluids, or fluids with firm bodies, are mixed together and grow hot. For some of these do not only begin to grow warm, but are even hot, nay burn with

^a Essay sur la Gradation de la Lumiere, Sect. 1. §. 7.

a vivid flame. Filings of iron, with an equal quantity of sulphur, kneaded into a paste with water, being lightly covered with earth, in a short time grows hot, then breaks out into flame. Let silver be dissolved in aqua fortis, and then precipitated by vinegar, and dried; this mingled with calx of pewter soon makes an effervescence, grows hot, is inflamed, and spreads a sulphureous odour around. Regulus of antimony mingled with mercury sublimate sometimes takes fire. Diaphoretick antimony vehemently burned with black soap in a covered crucible, and then suffered to cool, grows hot as soon as exposed to the air, and takes fire with a crack^a. *Geoffroy's* spirit of nitre mingled with all the oils of plants, being good and newly distilled, suddenly bursts out into a lively flame. In our commentaries upon the *Florentine* essays we have enumerated a great number of such bodies as excite an effervescence, and collect fire. Now these collections of fire arise only from the mutual attrition of the parts upon one another.

§. 823. Whatever body can long nourish and sustain fire, when once excited, or can encrease the same, is called the *pabulum* or *aliment of fire*; though in the mean time it's parts are attenuated and expelled by this action, and so are consumed as it were, and finally vanish.

§. 824. Pabula of this kind are all oils produced out of the earth, as petroleum, oleum terræ, naphtha, ambergrise, amber, sulphurs, fire-stones. Then all the oils of vegetables, expressed from any of their parts, or by distillation or fermentation reduced to spirits; resins either natural or artificial; coals. Then all the oils of the parts

^a L'Histoire de l'Acad. Royal. An. 1736.

of animals, whether they are found under the form of fat or tallow, or whether they are gathered by art from the solid or fluid parts, such as phosphorus.

§. 825. But all terrestrial fire stands in need of nutriment, nor can it continue by any means except it is fed. When this aliment feeds fire, it acquires parts most vehemently moved by the fire, and mutually rubbing one another, and their attrition and motion being encreased by their elasticity, they perpetually collect new fire, so much the more copiously as they are more elastic. Therefore neither water, which is not elastic, nor salts, nor earths, can be the aliment of fire, but only oils. The parts of these, which are much attenuated by fretting, and separated from the rest of the mass, fly off insensibly, and so the aliment is consumed.

§. 826. But the other grosser parts of the pabulum, being forcibly plucked away by the fire from the remaining mass, being aqueous, saline, oily, earthy, conjoined with but little fire and flying away, become a sensible elastic fluid, composed of the aforementioned parts, which we call *smoke*. This gathered under the form of soot, and re-exposed to the fire, may nourish it again till itself is rarified.

§. 827. But these same parts, in greater quantity and conjoined with a more copious fire, made red hot and volatile, and leaving the rest of the mass, constitute that which we call *flame*. Therefore smoke is very near flame, and is easily converted into it, provided a greater quantity of fire be present. Hence with the small flame of a lighted lamp we are able to raise a plentiful smoke from a heap of matter.

§. 828. Every flame is surrounded by an atmosphere, whose parts are chiefly watry, drove from the middle to the extremities by the force of the fire. This atmosphere is so much the farther expanded about the flame, as the pabulum is more aqueous. If we would unite the flames of two candles, the atmosphere of each very plainly appears, avoiding as it were this conjunction. For the parts of each are moved by an opposite motion, from the centre of the flame towards the circumference. Besides the ingenious *Hooke* has taught us^a, how it may be seen by help of a concave speculum.

§. 829. Flame ascends upwards, because it swims in the air, and the air's specifick gravity is greater than that of the burning parts, which are commonly rarified by a copious fire.

§. 830. Also flame is of a conical figure, adhering to the pabulum by it's wide base, and ending in a sharp top, from whence the smoke flies away, if any be there; that is, if the pabulum collected in a vessel is on fire. For where the flame adheres to the pabulum, the parts in it are most copious; it expels many of them on all sides from every one of it's lateral points, so that but few remain to ascend higher. Wherefore if by the help of a ring, through which the flame may pass, we obstruct the loss of the lateral parts, a greater quantity ascends upwards, and a longer flame is thereby made. Yet the flame is not hottest at it's base, nor at the top, nor in the middle; but if we look upon it, we shall see the lowest part to be darkest, a whiter follows, which is arched at it's upper part; this is the hottest; there follows a less bright and long apex, which is least hot of all.

^a *Cutlerian Lectures.*

§. 831. The purer the flame is, rising from a more homogenous pabulum, and smoking but little, so much the more vehemently it heats bodies. Therefore the flame of alcohol most of all heats those bodies to which it is applied. For the smoke of other flames, adhering to the bodies, greatly hinders them from being so much heated by the flame. This we are taught by many experiments made with the Pyrometer.

§. 832. If a flame is surrounded by another flame, as that of alcohol may burn in the middle of the flame of oil, then there are two fluids, one of which swims in the other. Therefore the middle flame acquires a figure which approaches towards a spherical, as a drop of oil in the middle of water.

§. 833. A fire being lighted in a terrestrial body, whether it be in the form of a live coal or of a flame, it will want aliment for it's preservation; and that it may succeed well with it's aliment, and the fire be preserved, it is requisite that the air of the atmosphere may have free access to it, and may press the pabulum with it's own force, neither greater nor lesser; also that the smoke, and the useless parts of the aliment, may be removed far from the fire, for otherwise the pabulum cannot feed it.

For if a burning coal of any dried wood, or of *Holland* turf, a lighted match, lighted odorous candles, also a wax candle, a tallow candle, a lamp furnished with linseed-oil, or rape-oil, or oil of turpentine, or any other distilled oil, or spirit of wine; if any of these should burn in a vessel, that will not allow free ingress to the air, they will be extinguished in a few minutes; and the smaller the vessel is, the sooner they will be extinguished: As likewise, how much the closer
the

the vessel is stopped, and the smoke hindered from going out; so the more smoke the burning body yields. Again, the less quantity of smoke is let out, so much the more such a body will feed the fire, as may be observed in a lighted match, and in the coals of *Holland* turf.

§. 834. All the enumerated bodies being lighted, and put under a large *Boylean* receiver, from whence the air has been well pumped, will much sooner lose their fire, than if the air had been left in the closed receiver.

Also the sooner the air is rarified, so much the sooner also will the fire be out.

§. 835. If all the same things on fire are shut up in a large receiver, into which fresh air is perpetually infused, and so the whole mass of air is condensed; they will preserve their fire something longer, than when left in the same air; yet however they will be extinguished. For more see Mr. *Boyle*^a.

§. 836. Wherefore that the pabulum may be proper for nourishing the fire, it is required that it may not be pressed too little or too much by the incumbent air, as also that the smoke may be removed from it. Therefore there will be in it some parts, which are very unfit for maintaining fire; these are chiefly watry vapour, also salts, and earths.

§. 837. How much the free access of the air is wanted, may appear from what follows. If a glass recipient, whose capacity is 95 cylindrical inches, be set upon a plain table, and shall have a round aperture above, whose diameter is 2 inches; a burning tallow candle whose diameter is half an inch shall continue to burn with a bright flame, till all the pabulum is consumed. Nay, when

^a Continuat. 11. Emper. physic. mech. art. 7.

the superior aperture of the same recipient was $\frac{1}{3}$ of a square inch, it continued burning, but not with so bright a flame. The aperture being diminished so as to be $\frac{3}{10}$ of a square inch, the flame was extinguished in a minute. It continued a few seconds longer, when the aperture was made $\frac{7}{10}$ of a square inch. But being made $\frac{2}{3}$ of a square inch, it went on to burn with a small dim flame, that hardly liquified and consumed the pabulum.

The thin flame of a wax candle continued to burn, but hardly emitted any smoke, having only a small aperture of half an inch square. As soon as this was diminished the flame decreased, and was soon extinguished, when only an aperture of $\frac{7}{10}$ of a square inch was left.

A flame being raised in a very fine cotton, whose pabulum was alcohol; the flame continued only for 2 minutes, with an aperture of $\frac{3}{4}$ of a square inch, and then went out. But when a greater flame was made, it hardly continued 10 seconds.

So that the flame of any pabulum whatever requires a free access of air, which will farther appear from the following experiments.

If a tallow candle of such a magnitude of which they sell eight to the pound, be put into an iron cylindrical tube, shut below but open above, having a length of 6 feet and a diameter of an inch; this burning at the bottom will be extinguished in a short time.

If an iron barrel of a gun be open at both ends, and through an aperture at the top be made to pass into a large *Boylean* receiver almost to the bottom, and in the receiver there shall be a burning candle; by means of the pump let the air be gently exhausted out of it, so that fresh air may enter continually; which that it may not rush in too violently, and by making a wind blow

out the candle, let it pass through three threads of cotton stretched over the upper part of the tube: the flame will then be extinguished in a few minutes, as the learned Dr. *Hales* has found ^a.

§. 838. Hence we may understand, why a culinary fire does not burn so well in hot weather as in cold.

For the air is hot, rarified, and less elastick, and therefore presses less upon the parts of the pabulum of fire, than cold air which is much more elastick.

If therefore the sun by it's heat should very much rarify and heat the air, which surrounds a burning coal, will this air be then able to drive the pabulum towards the fire? It will be hardly able to do it, and therefore the sun by it's splendor will seem to extinguish the coal.

§. 839. But may not certain particles be required, which swimming in the air, and hitherto unknown, must concur to constitute the flame of other bodies? This is not without probability, if we consider the experiments mentioned §. 837. and made in open vessels. For in those neither a too great rarefaction of the air, nor it's too great or too little pressure, nor the smoke hindered from going out, can be there alledged, but only a consumption of those parts in the air, whose presence was necessary to support the flame. Now let us consider some other things, which shall be proposed in the form of questions.

§. 840. *Why is a burning coal suffocated and extinguished, when plunged into cold spirit of wine, in the same manner as if it was water, nor does it inflame the spirit?* Because the spirit cannot be sufficiently heated to take fire. For if the spirit were first heated upon the fire, it would then soon be inflamed by the burning coal.

^a Vegetable Staticks, experiment 115.

2°. *Why does a blast of a certain force increase the power of the flame of the fire?* Because the flame being rarer is condensed by the blast into a narrower space. Hence a denser fire will have a greater force; which also obtains in the closer focus of a burning-glass.

3°. *Why does a greater blast blow out the flame?* Because it drives away from the pabulum either all, or the greatest part of the fire.

4°. *Why does water, when scattered all round with the greatest violence, and divided into very little drops like vapour, blow out the flame of houses on fire in a moment?* Because it performs the same thing as a most impetuous wind would do.

5°. *Why does water increase the fire, when poured upon the burning coals of a smith's forge?* It does it in this manner. When a small quantity of water is sprinkled upon the coals that are every where on fire, then the fire is drove from the upper part to that which the water does not reach. Just as a long iron bar, which is hot at one end and cold at the other, as soon as the hot end is plunged in water, it will grow hot at the cold end.

6°. *Does fire collect homogeneous things, and separate those that are heterogeneous, as was the opinion of the Peripateticks?* Not always. For it mingles several things when melted, as tallow, wax, pitch, resin: also it mingles all metals one with another, when melted by fire.

7°. *How does fire soften some things, as wax?* By removing their parts from one another, which the more they are removed, the softer the mass will be; till at last being totally dissolved, they swim as it were in the fire.

8°. *How does fire harden other things, as clay?* By expelling a great quantity of the fluid, which

which is interposed between the parts, so that the solid parts may touch one another by broader surfaces, and will have a greater quantity of coherence.

9°. *How does fire dry moist things?* By joining itself to the aqueous parts, by rarifying them, and by separating and driving them from the rest of the mass, which has a greater coherence.

10°. *Why do some things shine which are hardly hot, and others not shine which are much hotter?* Because they drive out the fire from them, not in right lines, but by a crooked and disorderly motion. And we cannot perceive light, unless when it strikes upon our eyes according to right lines.

11°. *Why is the flame of a tallow candle always at some little distance from the candle?* Because the tallow is cold, nor can it burn unless when melted and heated beyond 600 degrees. Hence that distance. For between the tallow and the flame of the candle, many degrees of heat intercede.

12°. *Why does the cotton grow black, after it has burned some time in the flame?* Because it comprehends both it's own coal and that of the tallow: as evidently appears from burning lamps which are fed with oil.

13°. *Why is a candle, which has burned some time and is then extinguished, more easily lighted again than a new one?* Because the cotton, which is now become black, presently absorbs the fire into itself; whereas the white cotton repels the fire from it, by §. 808.

14°. *What is heat in bodies?* A certain quantity of fire in motion in the interstices of the parts, and concealed in the pores of the particles. And therefore bodies are so much the hotter, as they contain more fire in motion.

15°. *When*

15°. *When do we discover bodies to be hot by our touch?* When there is more fire in motion in the bodies, than in the nerves of our organ of touch, or in their fluid. Hence we judge the same body, and of the same degree of heat, sometimes to be warm, sometimes to be hot, and sometimes to be cold, according to the different disposition of the organ of the sensorium.

16°. *What is heat in us?* A perception of the mind, raised by a certain motion of fire, which is excited in the nerves of the organ of touch, or in their fluid.

17°. *Bodies that are made hot, and tied or laid upon cold bodies that are solid and large, why are they extinguished without consuming the pabulum? But the same being laid upon bodies that are rare and small, why are they entirely consumed?* The first happens, because the fire cannot sufficiently shake and attenuate the parts of the pabulum, so as that it may become it's nutriment; their motion being presently suffocated by the parts of the other solid, or at least being too much diminished. This will not obtain when the body made hot is put upon the other rarer body.

18°. *Is fire a body of it's own kind, or may other bodies also be converted into fire?* It seems to be a body of it's own kind. First, because we know no other body so subtile. Secondly, because it equably distributes itself through all bodies and spaces. Thirdly, by no experiment it appears, that fire converts other bodies into fire, though they may be it's aliment. For the focus of the sun's rays, which is most pure fire, cannot be seen. But the flame of burning alcohol is clearly perceived, and produces effects which are very small, in respect of that focus: and therefore that flame is not pure fire. Nay, if it burn in a glass receiver,

receiver, much vapour will be collected by the sides. Alcohol being agitated for the space of two hours in *Papin's* digester, by no means could be converted into fire. Fourthly, if bodies could be converted into fire, it's quantity would increase upon earth, so that at last the whole world would become fire, and all things must perish, since fire is wanted only in a determinate measure, for the vegetation of plants, as well as for the life of animals. But the doctrine of fire affords so ample and fruitful a field, that there would be no end if we would treat of it at large.

19°. *Now what is absolute cold in bodies?* The absence of all fire, and therefore nothing positive.

20°. *When do we perceive bodies to be cold?* When their parts are less moved by fire, than our nerves, or their fluid.

21°. *Therefore what bodies refrigerate?* Such as can expel fire from others, or reduce it to rest with the parts of bodies, or to lesser motion. This comes to pass when we mingle water with volatile alkaline salts, and others, as nitre, sal polychrestum, vitriol, sal gemmæ, sea-salt, alum, and chiefly sal ammoniac, or it's flowers. Also if with snow, or slices of ice, we mingle any of the aforementioned salts, or salt of tartar, pot-ashes, faccarum saturni, borax, Glauber salt, sugar, fel vitri, quick-lime, souda: with all which things the industrious Mr. *Reaumur*^a made very accurate experiments, by help of a Thermometer shewing the degrees of the cold that was excited; and likewise Mr. *Nolet*^b. Also cold may be procured, if to snow or ice be poured spirit of wine, of sea-salt, vitriol, vinegar, spirit of sal ammoniac, and of urine; but especially if spirit

^a L'Hist. de l'Acad. Royal. An. 1724.

^b Philos. Transf. N. 449.

of nitre be poured to it, for then a terrible degree of cold will arise, which is 72 degrees below the mark of freezing in the scale of the Thermometer of *Fahrenheyt*. If there be taken vinegar, spirit of vinegar, vinegar of verdegrease, omphacium, juice of citrons, or of oranges, and if any one of these fluids be mingled with the purest volatile alcali, such as is the volatile salt of human blood, urine, harts-horn, &c. there arises a great effervescence with a notable degree of cold, as the learned Dr. *Stare* has found^a. And after him several chemists have confirmed it^b. Oil of vitriol, or spirit of nitre, poured upon sal ammoniac, have produced the same effect.

22°. *Therefore does not all cold depend upon frigorific particles, that expel fire, and succeed into its place; as Gassendus, Boyle, de la Hire, Ramazzini, and Nieuwentiit have thought?* Not all: for it is sufficient that fire, which always affects an equable dispersion, should go out of a body that is hotter than those about it, that this may be cold, though nothing else should succeed in the place of fire; and so generally bodies will grow cold. Though it cannot be denied, but that there are such corpuscles, which on some occasions expel fire out of bodies, and so may be called frigorific, as has been made appear in what goes before.

C H A P. XXVII.

Concerning the general properties of light.

§. 841. **W**E have mentioned already, that fire has the faculty of *shining*, as well as of rarifying and heating bodies. This

^a Philof. Transf. No. 159.

^b Boerhaave *Chemiæ*, Tom. 2. p. 533.

property we shall briefly examine in some of the following chapters.

§. 842. Whatever gives occasion to the mind to *see*, by the mediation of the eyes, is *light*; which either enters the eyes directly, as it is emitted by the shining body, or is reflected by illuminated bodies. By the help of light we see shining objects, and objects that do not shine; as also quantity, figure, place, situation, distance, continuity, separation, motion, rest, and colours. When light is absent, we see none of these things. Now that we may see the things aforementioned, it is necessary that the eye should be placed at some notable distance from the objects.

§. 843. The least shining spark may be seen at every point of the superficies of a sphere, in the center of which the spark is placed. A dark obstacle being interposed in the right line between the spark and the eye, the light cannot be seen. Wherefore it is seen as it were by rays, which are emitted from the center of the sphere to all it's circumference.

§ 844. For this reason philosophers have called that light, which is brought to us in right lines, *rays of light*.

§. 845. The subtilty of these rays is vastly great, and very nearly approaching to geometrical lines. For if a small hole be made with a needle in a paper, a spectator lying on his back, and looking through this, may see all the objects in the celestial hemisphere. And when he stands upright, he may see a fourth part of the heaven, together with all the bodies that are before him upon the ground. So that an innumerable quantity of rays either emitted or reflected from objects, passing through a very small hole, shews the extreme subtilty of light, such as is not to be comprehended by the utmost subtilty of the human mind. Secondly,

Secondly, if a common tallow candle be lighted, and set by night on the top of a high tower, it may be seen all round at the distance of half a mile from the tower. Wherefore there is no place within a sphere of a mile diameter, in which the eye can be placed, where it will not receive a ray of light from this little flame. All these rays were before concenter'd in the flame, which as it is exceeding small in respect of the sphere that is illuminated, it proves the immense subtilty of the rays of light.

Thirdly, light also passes through the pores of a diamond, of gems, and of glass, which are so very minute, as that hitherto they have not been perceived by the best microscopes.

§. 846. The length of shining rays is almost infinite. For they are not only extended from the sun to the earth, which are so far distant from one another, that a bullet shot from a gun with the most rapid velocity, could hardly measure this distance in 25 years; but rays are also extended to us from the remotest fixed stars, the distance of which is vastly greater than the former. For since by Dr. *Bradley's* last observations, the angle of the annual parallax is found to be not greater than one second; the distance of the fixed stars will be so great, that a cannon ball could not describe it in less than 104166666636 years.

§. 847. Because at this immense distance the stars shine with a most vivid light, the strength of the rays will be but very little if at all diminished. Which can by no means be conceived, had not the rays passed through an empty celestial space, which is not at all resisting, nor can it reflect or intercept light.

Tab. 11.
Fig. 11.

§. 848. Because light proceeding from a spark, or from any shining body, goes on in right lines, as it were from a center through the whole ambit of a sphere, it must move in right lines that diverge from one another. Some of these, as SA, SE, diverge more from one another, and others less, as SA, SB.

§. 849. Because of this divergency of the shining rays, the density of light will decrease at a greater distance from the shining center, and that in a subduplicate ratio of the distances from the center. This is proved by a like demonstration to that in §. 228. Also this may easily be demonstrated to the eye by many experiments, as well by means of the sun's rays, as of those of a candle.

§. 850. Light is emitted from every shining body, and moves with prodigious velocity.

Tab. 11.
Fig. 1.

From observations of the eclipses of Jupiter's satellites, this has been demonstrated by *Romer*. Let A be the sun^a, BCDE the annual orbit of the earth, F Jupiter, HGN the orbit of the inmost satellite, G the satellite entering the shadow of Jupiter, H the same coming out of the shadow. If the earth being at B, the satellite is seen to come out of the shadow, after $42\frac{1}{2}$ hours a like emersion will be again observed; and if the earth were always to remain at B, within 30 times $42\frac{1}{2}$ hours 30 emersions would be seen. But in the mean time let the earth withdraw farther from Jupiter, and more to C; then if light requires any time in it's course, the emersion of the satellite will be observed later in C, than before it was observed in B, and this must be added to the time of $42\frac{1}{2} \times 30$ hours, which light requires in passing

^a Hugen. de la Lumiere, c. 1.

over the space MC, which is the difference of the spaces CH and BH. The observations of many years have shewn, that this time is very notable, even ten minutes or more. From whence we may infer, that light takes up the space of 8 minutes and 13 seconds, according to the celebrated Dr. *Bradley*, to describe the distance which is between the sun and the earth. And though some inequalities of time may arise, from the excentricities of the orbits of the satellites, these cannot agree in all the satellites, nor in every situation of the earth in it's orbit.

Secondly, the later astronomers have discovered, that the fixed stars are subject to some aberrations, the order of which cannot be represented by the annual parallax, nor depends on refractions, nor on the nutation of the earth's axis; but may be easily and clearly explained, if a successive motion be ascribed to light, from the fixed stars to the earth, and an annual motion about the sun be ascribed to the earth, as the most sagacious Dr. *Bradley* has very elegantly demonstrated^a: whose doctrine remains unshaken, notwithstanding the difficulties some have raised^b. For to maintain the earth to be immoveable, and the sun to move about it, from the authority of the fathers, at this day is only to make sport in a serious affair. Nor are those passages of much greater weight, which are fetched from the sacred scriptures, and are either ill understood or perverted, as has been long ago proved by many authors^c.

Tab. 11.

Fig. 19.

^a Philof. Transf. No. 406. Smith's Opticks. b. 4. c. 7.

^b Comment. Bonon. p. 627.

^c Velthuisius de quiete solis. Horrebovii Copernicus triumphans.

Thirdly, that light has motion may be still farther evinced by other arguments. For what else is light but fire, moving in right lines, and entering our eyes? But fire moves, as has been proved in the foregoing chapter. Fire adhering to bodies moves together with them, when they become volatile, as appears from hot vapours ascending, and from hot smoke. Besides all things that burn and shine are consumed, and fail at last, which could not be done unless by the emanation of light and of combustible matter.

Fourthly, do we not distinguish the beginning of lightning, and it's beams, and it's end, though the light moves exceeding swiftly?

Fifthly, though the light of the sun consists of rays almost parallel, yet by means of a concave spherical speculum we can divert this parallelism, and make it converge to a focus; which departure from it's former course could not be effected, without a motion of the rays. And that the rays are most vehemently moved appears from their most violent action.

Sixthly, we can also separate the rays of light from one another, as well with concave spherical glasses, as with prisms, and direct the light to any place where it was not before. This could not be done unless light had motion, and darted from the shining body.

Lastly, in refractions through different mediums the rays of light are accelerated and retarded, and are therefore moved.

§. 851. Hence the doctrine of the most acute *des Cartes* falls to the ground*, who conceived light as diffused through the universe, which was full of bodies, and pretended that it was pressed

* Dioptr. cap. 1. §. 3. & in epist. 17. par. 2.

by the shining body, by which pressure it was perceived by the eye placed at the other extreme of the ray, and therefore was not emitted. But according to this hypothesis there could be no darkness; for as light is a fluid, it must be subject to the laws of fluids. But we may observe, if a fluid included in a vessel is any where pressed, that pressure is propagated according to all directions. So that whether the sun continues above the horizon, or whether he sets below it, if the eye were open it must be affected by it's light; which is contrary to all experience.

§. 852. If we consider with an attentive mind that vast rapidity with which the light of the sun is moved, and the small effects it produces upon the bodies it illustrates, we shall find another argument for demonstrating the vast subtilty of the particles of light. For since the sun is distant from the earth 24000 of the earth's semi-diameters; and the semi-diameter of the earth is 19615782 feet, according to the measure of some late geometricians^a; the distance of the sun from the earth will be 470788768000 feet. These are described by light within 8 minutes and 13 seconds; so that $980809933\frac{1}{3}$ are described in the space of one second. A cannon ball shot off with the greatest violence describes 600 feet in a second; so that the velocity of light will be to that of a cannon ball, as 1634683 to 1 very nearly. Suppose that ball to be of 10 pounds weight, or 76800 grains; this weight multiplied by the square of it's velocity exhibits it's force. The square of this velocity is 2672188510489. Wherefore if a particle of light had only so much weight as $\frac{1}{34794121}$ part of a grain nearly, it would have

^a Suite de l'Hist. de l'Acad. An. 1719. part. 2. c. 5.

the same force as the cannon ball of 10 pound now mentioned. But this operates vehemently upon all bodies in it's way, destroying every thing it meets: and a particle of light would do the same, of the magnitude now mentioned. But since the light of the sun, shining upon the very tender leaves of flowers, does not tear them in pieces, but only moves the juices lightly in them; it will follow of course, that the subtilty of it's particles are vastly great, and almost infinitely less than the assigned part of a grain. Perhaps therefore the intire ray, extended from the sun to the earth, will not be equal in weight to a grain. Wherefore the light emitted from the sun through the whole planetary system, by reason of it's immense subtilty, will give no obstruction to the light of other shining bodies.

§. 853. An intire ray of light, emitted from a shining body, consists of light moving successively from space to space, and at the same time of other light contemporaneous to it. For an intire ray of light is like a bundle compounded of other little rays, each of which is endued with it's own immutable colour, all which joined together are united in the same ray.

§. 854. Light is a most fluid matter, and therefore like other fluids consists of particles not cohering with one another, and meeting with an opaque reflecting body, it is reflected according to any angle, and according to the same laws that other bodies are reflected, when they meet with an obstacle.

§. 855. When many rays of light reflected from different objects, pass through a small hole, and every one of them paint the image of that point of the object from whence they proceed, together with the colours of the object, upon any
white

white plane that receives them; it appears that the light is not blended in this hole, nor confounded with other light; nor does one sort of light disturb the motion or direction of any other sort. Whence the rays have as it were the perfect rigidity and immutability of solid threads, stretched out from the object, from whence they are derived, to the plane that receives them.

§. 856. Many things in this doctrine may be queried, the reasons of which we can only attain by conjecture. Such are

First, how do light and fire differ? Is it in substance, or only in the magnitude of their parts, or in the direction of their motions? Perhaps not in substance, nor in the magnitude of their parts, since a great quantity of light collected together has always the characters of fire. But fire does not shine, unless when determined to the eye in right lines. A silver spoon something heated does not shine in the dark; but if you put diamonds or crystals into it, though they did not shine before, yet they soon begin to shine, expelling the fire they had received under the form of light. They do the same thing, if thrown into hot water ^a.

Secondly, can earthy bodies by division or attenuation be changed into light? Perhaps attenuation alone will not suffice, but there is also required the same solidity, figure, mobility, and magnitude of parts, all which things if they could concur, then from not shining bodies they might become shining. But this seems not likely ever to happen, if we have regard to the properties of fire, and to it's equable distribution through all spaces and bodies: and if at the same time

^a L'Hist. de l'Acad. Royal. An. 1735.

we consider, that bodies are not changed into fire. §. 831. No. 18.

Thirdly, how is it that light proceeds from shining bodies, as from the sun, or from a lighted coal? Is it not because the solid parts of these bodies, though removed from one another by light, approach to one another by their attracting force, and by approaching expel the intercepted light, with such velocity as we find it to be emitted? The difficulty lies in the extreme rapidity of light. But the attracting force is a pressing power, light is the obstacle, and therefore by §. 166. it is $P = OC$. Now P remaining the same, and O decreasing, C will increase; so that if O becomes a quantity almost infinitely little, C is required to be almost infinitely great. But then how is light darted out of a flame, in which the foregoing reasoning seems to have no place?

Fourthly, does light flow out of every shining body with the same velocity? This appears by no observation, and perhaps the difference of velocity is great, by which light is expelled from bodies, according to the different force with which their parts attract one another. And yet it should follow from Dr. *Bradley's* observations, that light is projected from the sun and fixed stars to the earth with equal celerity.

Fifthly, when light is reflected by an opaque body, does it preserve the same velocity after reflexion, as that with which it was emitted by the shining body? If the angle of reflexion is equal to the angle of incidence, the light will have the same celerity. Dr. *Bradley's* observations seem to evince, that light sent directly to us from the sun, and that reflected by Jupiter's satellites, always retains the same velocity.

Lastly,

Lastly, do not those bodies shine most easily, which abound with oily and sulphureous parts, as soon as they begin to move by friction, percussion, putrefaction, vital motion, or by any other cause? For what reason does the sea shine, when tossed by the winds? or the back of a cat, the neck of a horse, when rubbed contrary to the natural situation of the hair? or wood, flesh, fish, when rotten? the eyes of animals and glow-worms? Also a glass ball in violent rotation, and rubbed by the hand, why does it emit a blue light sticking to the hand?

C H A P. XXVIII.

Of refracted Light.

§. 857. **W**HEN light emitted from shining bodies, passes either through empty space, or through any body whatever, either firm or fluid, it is said to pass through a *medium*: for so that is called whatever it is, that affords a passage for light.

§. 858. If the medium be homogeneous, and every where of the same density; as soon as light has entered into it, it goes on in a right line from it's first point of entrance till it's going out, with whatever direction it began, as far as can be collected from observation.

§. 859. If light passes out of one medium into another, which attracts it with a greater force, the velocity of light will be increased. For the medium acts with an attracting force upon all the particles of light in a direction towards itself, so that the light is carried to this medium partly by it's own velocity, and partly by that which it acquires by the attracting force,
for

for which reason the velocity of the light will increase.

§. 860. If a ray of light is carried by a perpendicular direction out of one medium into another, which is more attracting, it will pass on in the same right line being produced.

Tab. 11.
Fig. 2.

For let the medium be X, out of which the ray R F is carried into a medium Z, which is more attracting, whose superficies is A B: from this let an attracting force proceed, extended as far as C D, which acts in right lines perpendicular to this superficies, and the space of attraction will be C D A B. Therefore the ray R F arriving at O, will be carried both by it's own motion, and also by the attracting force, which acts in the same direction O E, and will proceed in it's former course R O E, though now actuated by an accelerated motion.

§. 861. But if the same ray of light is carried out of the medium X into the other Z by a direction R O K, which is oblique to the superficies A B; it will depart from it's former course, and will enter another O F; which departure is called *Refraction*.

Tab. 11.
Fig. 3.

For as soon as the ray arrives at O, it is carried by a double motion, O K which is it's own, and O S by the attracting force; so that it will proceed in the course O F, which is the diagonal of the parallelogram O K S F, by §. 357.

Tab. 11.
Fig. 3.

§. 862. Because O F approaches nearer to the perpendicular O S, to the superficies of the medium A B, than O K; it is a *refraction towards the perpendicular*, as often as the light falls upon the superficies of a medium more attracting than that out of which it came.

§. 863. If the ray of light R O out of a medium more attracting, falls obliquely upon the superficies

superficies AB of a medium less attracting Z , it is a *refraction from the perpendicular*.

For if CD be the limit of a more attracting medium X , operating towards AB , the ray RO going out of the medium X cannot continue its course ROK , for it is influenced more by the force of the attracting medium X than by Z , and that in the direction MO ; by which if it is moved by the quantity KL , while in the mean time it would be carried from O to K , being acted upon by this double motion it will tend from O to L . By going this way it will depart more from the perpendicular OM than OK . Tab. 11.
Fig. 4.

§. 864. Because the attracting force, which proceeds out of bodies, is greatest in their superficies, and decreases as the distance is greater from it, by §. 498. before the ray of light out of a rarer medium enters into a denser, or out of a denser enters into a rarer, it will be carried in a small curve line; and then being acted upon as much as may be by the attracting force, it will pursue its straight course.

For let the ray be Rr , which out of a less attracting medium is carried obliquely to the superficies GG of a more attracting medium, and let the limit of attraction be MM , which attraction acts in right lines perpendicular to the superficies GG . Therefore the ray RA falling into the attracting force, will be turned out of its way Rr into another Aaa . But arriving at b , which is nearer the superficies GG , and being more attracted, it enters into the way bb ; from whence being carried to c , where again it is more attracted, it will be carried in the right line cc . And since all these right lines a , b , c , are very short, they will compose a curve. And as the attracting force is extended but to a small distance Tab. 11.
Fig. 5.

Tab. 11.
Fig. 6.

stance from the superficies GG , this curve will be a very short one. For as soon as the ray enters the superficies GG , it is no longer turned out of it's way, as being now acted upon by the attracting force as much as can be, which is equally diffused through the whole medium. In like manner a ray going out of a more attracting medium into another that attracts less, will be moved in a curve, which will have a contrary position to the former, in which GG is the superficies of the more attracting medium, MM is the limit of it's attraction, and the ray Ra , attracted continually towards GG , is carried in the curve $abcd$, and at last proceeds in the right line dd . If this medium between GG and MM be a vacuum, the ray will proceed towards GG by the whole force of the attracting body GG . But if after GG there should be a medium, which is something attracting, though less than GG , the attracting force of the medium GG will be lessened, because they both act with contrary directions. So that GG will only act upon the rays by the excess of it's force, which the lesser it is, so much the less refraction will be produced.

§. 865. We have already proved in §. 498, that the rays approaching to the more attracting medium will be inflected before they arrive at that medium; when the light of the sun passes between the edges of two knives. For then it will be something turned out of it's straight way, and so much the more as those edges approach to one another.

Secondly it is proved, that the rays are inflected at their entering into a rarer medium out of a denser. For when we look obliquely upon a plane glass, or the lens of a long tube placed aloft

in

in the air, there seems to be a double image of objects that are on high, and are placed before us; one of which vanishes, as soon as the lower surface of the glass is touched by water or oil. For the ray *Ra* now entering the air out of the glass *GG*, by the great attractive force of the glass, would be turned out of it's way *aa* into the curve *abcde fghik*, and returning into the glass, and passing on in the direction *kK*, would represent the other image of the object: but as soon as the lower superficies of the glass *GG* is tinged with water or oil, the ray *Ra* will be drawn downwards by these. Therefore the force of the glass being diminished, the inflected ray will not return, but rather goes on in the right line *aa* or *bb*, by which the other image of the object vanishes.

Tab. 11.
Fig. 7.

§. 866. From whence it manifestly follows, that the refraction of light depends upon the attracting forces of the mediums. Which forces are generally in proportion to the densities, except in the case of some oily and inflammable bodies, which attract in a greater ratio, as *Newton*^a, *Hauksbee*^b, and *Hellsam*^c, have proved by many experiments. For oil of wax is of a very small weight in respect of butter of antimony, being as 662 to 1976; whereas the ratio of refraction in both is as 6685 to 5941, that is about 1,16 to 1. Therefore the refraction is not always in the ratio of their gravities.

§. 867. The true cause of refraction being now found, the opinions of other Philosophers are easily discussed, which by no means agree with

^a Optices, L. 2. Par. 3. Pr. 10.

^b Phys. Mech. opp. §. 10.

^c Lectures, p. 292.

Tab. 11.
Fig. 8.

the experiments. M. *Des Cartes* had ingeniously observed, that the path of the ray RO was to be resolved into RC , parallel to AB , and into CO , perpendicular to the same. Then he imagined, that light obtained an easier passage through a denser medium than through a rarer, as being in it's motion less disturbed by a medium whose parts are less moveable. Therefore if light is carried out of air X into water Z , it will be accelerated, so that in an equal time it will not describe an equal path OC , but some greater OD . Then drawing DF equal to RC , it will move in the right line OF , by approaching towards the perpendicular CK . But how shall the ray be accelerated in the medium Z , which is brought thither with the celerity CO ? Nay, though all resistance be taken from it, yet no acceleration will follow; for to this purpose some new cause is required, which shall produce a new motion. Secondly, how can any one conceive also, that when light passes through denser media, nay through firm bodies, that it shall meet with less resistance, and be less retarded, than when it passes through rarer and fluid media? Yet this was the opinion of *Des Cartes*. Thirdly, as this Philosopher supposed the firmness of bodies to consist in the rest of their parts, will the parts of glass or of amber have any difference of rest? Yet they have different powers of refracting light: that of amber to that of glass being as 13654 to 5436. Fourthly, there are some fluids that refract light more than firm bodies, and other fluids which refract less; in which case the opinion of *Des Cartes* can have no place.

Tab. 11.
Fig. 9.

§. 868. *Dechales* considers a ray of light $DCAB^a$ as compounded of small rays something cohering

^a Dioptr. L. 1.

together,

together, and observes the refraction to be made towards the perpendicular, when the ray passes out of a rarer medium into a denser or more resisting E B, because it's part B sooner finds a resistance than A ; therefore B can only move by the quantity F B, whereas A being less retarded can move in the same time a greater quantity A G. Therefore the ray will be inflected towards the perpendicular G I, so that when the angle of incidence is C B H, that of refraction will be K G I. But it is not favourable to this opinion, that light is more refracted by water than by glass, crystal, *sal gemmæ* ; and still much more by rectified spirit of wine than by water, to which no one will ascribe a greater resistance than to solid glass. But this excellent geometrician is to be excused, because he ingeniously confesses, that he does not entirely acquiesce in his own opinion. Dr. *Barrow* in his *Optical Lectures* was of the same mind with *Dechales*, or rather was followed by *Dechales*.

§. 869. Other Philosophers have taken other methods to explain refraction ; but those who have had recourse to a different resistance, or have made it greater in fluids than in solids, or on the contrary ; have never been able to account for the experiments of *Newton* on these principles. Nor have they met with more success, who have attempted to explain the matter by some mechanical principle. For refraction depends on the attracting force of the medium, which is not mechanical, but is singular in every body, nor does it always follow the proportion of the corporeal mass.

§. 870. Because a ray of light, when arrived at another refracting medium, describes a very short curved line ; for the sake of easy conception

Tab. 11.
Fig. 8.

in what follows, we may suppose it to move in a right line quite to the superficies of the refracting medium. Therefore let X be a rarer medium, Z a denser, it's surface AB, upon which let a ray RO fall obliquely, and the perpendicular COK being drawn to the superficies AB, RO will be called the *incident ray*, and ROC the *angle of incidence*. And RC, perpendicular to OC, will be the *sine of the angle of incidence*. Then OF will be the *refracted ray*, DOF the *angle of refraction*, and the perpendicular DF will be the *sine of the angle of refraction*.

§. 871. With whatever inclination the ray may fall upon the refracting surface of the other medium, there will always be a constant and immutable ratio between the sines of the angles of incidence and refraction.

Tab. 11.
Fig. 8.

For if RO denotes the velocity of the incident ray, this will be constant. But this may be resolved into RC and CO, by §. 357. The ray will not be accelerated as to it's motion RC parallel to AB, but only in it's motion CO. Let it be accelerated by the quantity DK, taking $OI = OH = RC$, and let fall the perpendicular IS, and KS perpendicular to OK. Then drawing OS, it will denote the velocity of the refracted ray, which also will be constant. Then raising the perpendicular DF, it will be OS to $FO = RO :: SK = OI = RC$, which is the sine of the angle of incidence, to DF the sine of the angle of refraction. And therefore because RO and OS are constant, DF and KS will be constant also.

§. 872. These sines are in a reciprocal ratio of the velocities in these mediums.

§. 873. *Snellius* found that there was a constant ratio of refraction, but he used the secants of the

the compliments instead of the sines. Let the perpendicular BL be drawn at the extremity of the diameter AB, and let RO be continued to the tangent in E, and OS as far as L. Then OE will be the secant of the angle BOE = ROH, and OL the secant of the angle BOL. Then drawing FP perpendicular to AB, it will be OE. $OB :: OR . OH$, and also $OL . OB :: OF . OP$. Therefore $OE \times OH = OB \times OR$: and $OL \times OP = OB \times OF$. Therefore $OL \times OP = OE \times OH$, and $OL . OE :: OH . OP$. Therefore the secant of the complement of refraction is to the secant of the complement of incidence, as the sine of incidence to the sine of refraction.

§. 874. *Cartesius* making use of this invention of *Snellius*, first applied the sines, and therefore introduced no small light and convenience to this doctrine. The ancients observed a difference in the angles of refraction, according to the various inclination of the incident ray, and constructed tables of refraction with great labour, for the various inclinations of the rays of incidence: which tables may now be well spared.

§. 875. Mr. *Cassini*^a and Sir *Isaac Newton*^b have also confirmed the constant ratio of the sines by various experiments. Nor is it any matter whether light proceeds out of a rarer medium into a denser, or on the contrary.

§. 876. It is demonstrated in plain trigonometry, that in every right-lined triangle ABC, the sines of the angles are proportional to the sides which are opposite to those angles. But if in two triangles ABC, CBE, the angles BAC and BCE are very small, whose sine is the same line

Tab. 13.

Fig. 3.

^a Ep. 2. Astronom. de Solis Refractione.

^b Lectiones Opticæ.

BE; the angles will be in the reciprocal ratio of their sides. For the angle BAC is to BCE, as the sine of the angle BAC to the sine of the angle BCE, that is, as BC to BA, or as EC to EA.

Tab. 11.
Fig. 10.

§. 877. Light emitted from the sun A, first passes through the celestial spaces, or through an empty medium, as it proceeds towards the earth, then obliquely into the earth's atmosphere B, or into a denser medium, and is refracted towards the perpendicular. But whereas the density of the air, the nearer it is to the earth, is perpetually increasing, the refraction of the light will also increase in the places C, D, E, F, in which there is continually a greater density. Wherefore as the light passes through the various densities of the atmosphere, it will describe a curve BCDEF: and because in the same altitude from the earth, the density of the air changes every day, and because the air is always more or less accumulated by exhalations and vapours that refract light in different manners; the path of light through the air will be very inconstant, and will be neither a cycloid, nor an epicycloid, according to *de la Hire*^a, as *Hermannus* has proved^b: and which *Dr. Taylor* has therefore endeavoured to determine after another manner^c. That the refraction of the atmosphere was continually different, was observed by *Nettleton*^d, who measuring the height of a hill in cloudy and wet weather, found a greater angle than in a dry and serene season. Also the tops of hills, when viewed from the same place, appear to be higher in a morning or evening, than at a clear noon.

^a L'Hist. de l'Acad. Royal. An. 1702.

^b Act. Lips. An. 1706.

^c Method. Flux. invers. prop. 28. prob. 22.

^d Philos. Transf. No. 388.

And

And in the winter they are observed to be higher than in summer. That the air does really refract light that passes through it, *Lowthorp*^a has proved by several experiments, and afterwards *Halley* and *Hauksbee*^b, as also *de l'Isle* in *France*^c; the astronomical observations would suffer no doubt to be made of it, which shew the stars to be higher above the horizon than they ought to be, as also the appearances of the sun and moon above the horizon, when they are really under it; and also the morning and evening twilights. From this refraction of light it follows, that we never see the heavenly bodies in their true places, but always higher, so that A is seen in L; except when they culminate.

§. 878. If a ray of light out of air fall obliquely upon water, it is refracted towards the perpendicular. In which refraction the sine of the angle of incidence is to that of refraction, as 9434 to 7071, or as 4,002 to 3, that is nearly as 4 to 3, according to *Newton*^d. This proportion obtains among those rays that are emitted from the sun, and which fall upon water, which being refracted exhibit a green colour. Among the rays passing through the air, and refracted by glass, the ratio of the sines is as 8097 to 5240, which is nearly as 17 to 11^e. But rays of other colours have a different degree of refrangibility; for the red rays are least refracted, and the violet most. So that the sines of these incident and refracted rays are to each other as 80481 and 81656 to 524000. This most illustrious Philosopher, in his Optical

^a Philof. Transf. No. 257.

^b Phys. Mechan. Exp. p. 175.

^c L'Hist de l'Acad. Royal. An. 1719.

^d Lect. Opt. p. 1. Sect. 2. §. 35.

^e Newt. Lect. Opt. p. 1. Sect. 2. §. 30.

Lectures, has delivered various and very accurate methods of measuring the refraction of light, as it passes through different media; which deserve to be consulted.

§. 879. In the mean time we may observe, that when light falls upon any corporeal medium, it does not all pass intire, but some part of it is reflected by the repelling force of the medium: so that behind it unrefracted light may be always observed. It is plain that air reflects much light, because a ray of the sun being viewed side-ways may be perceived. A vessel full of water, of spirit, or oil, and even glass itself, intercepts more light. How much is the loss of light, when it passes through glass, sea-water, &c. Mr. *Bouguer* has endeavoured to determine by ingenious experiments^{*}.

§. 880. Wherefore since corporeal media, though ever so thin, intercept so much light, it can by no means be imagined, that that which comes to the earth from the most remote fixed stars, can pass through a corporeal medium. For it would all be soon reflected and lost in such an immense intermediate distance, either by the solid particles of the medium, or by their repelling force. Now since the fixed stars are observed to shine so bright, their light must necessarily pass through empty celestial spaces, till it arrives at the earth's atmosphere.

^{*} Essay d'Optique, Sect. 1. §. 3.

C H A P. XXIX.

Of light falling upon the plain and spherical surfaces of refracting media.

§. 881. **B**ECAUSE light proceeding from Tab. 11. a shining body S, or reflected from Fig. 11. an opaque point S, goes on like the rays SA, SB, SC, SE, emitted from the center of the sphere S; the rays will perpetually recede from each other, forming an angle. These are called *diverging*, and the greater angle they form, they are said to be still *more diverging*. Thus SA and SE diverge more than SA and SB. And in general they are called *diverging*, whenever they recede more from one another, though they do not proceed from the same point.

§. 882. The shining point S, or the opaque reflecting point, is called the *radiant point*.

§. 883. The rays that are at a distance from one another, and continually approach nearer to one another, are called *converging*. Such as AS, CS, ES would be, proceeding from A, C, and E.

§. 884. The point or place, in which the converging rays meet, is called the *focus*.

§. 885. The point or place, in which the converging rays would have met, if they could have gone on in the same medium; or the point, from whence the diverging rays would have proceeded, had they been continued, is called the *imaginary focus*.

§. 886. If rays of light not much diverging, AD, AC, AB, fall upon the plane superficies SD, Tab. 11. of a denser medium Z than X from whence they Fig. 12. come, are refracted towards the perpendicular, being carried in the right lines BE, CG, HD, which

which being produced backwards proceed as it were from the imaginary focus O , more remote from the superficies SD . The distance AD from the radiating point A , is to OD the distance of the imaginary focus from the superficies SD , as the sine of the angle of refraction to the sine of the angle of incidence.

For AD perpendicularly falling upon SD , passes strait to H without any refraction. The ray AC falls obliquely upon SD , upon which let be drawn the perpendicular Cp . Then will GCp be the angle of refraction, to which COD is equal. But by §. 876. the sine of the angle COD is to that of CAD , as CA to CO , that is, as DA to DO . But the angle CAD is equal to the angle of incidence ACq . Therefore the sine of the angle of incidence is to that of refraction as OD to AD .

Tab. 11.
Fig. 13.

§. 887. If rays of light not much diverging, KM , KR , KT , fall upon the plain superficies VS of a rarer medium than that from whence they came, they are refracted from the perpendicular KM , and tend to MN , RP , TQ , which protracted backwards meet in the imaginary focus L , which is nearer the superficies VS than the radiant point K , and the distance KM to LM , from the superficies VS , is as the sine of the angle of refraction to the sine of the angle of incidence; which is proved by the same demonstration as in §. 886.

This demonstration will not obtain in rays that have much divergency; for these protracted backwards will have a small circle for their imaginary focus, which will be so much the greater as the rays are more diverging.

Tab. 11.
Fig. 12.

§. 888. If the converging rays EB , GC , HD , fall out of a denser medium Z upon the plain superficies

perficies SD of a rarer medium X , they are refracted from the perpendicular, and will form a focus A which is nearer the superficies SD than the imaginary focus O ; and the distance AD will be to OD in the same ratio as in §. 886. Therefore these rays become converging.

§. 889. But if the converging rays NM , PR , QT , out of a rarer medium into a denser, fall upon the plain surface SV , they will be refracted towards the perpendicular, and will meet in the focus K , which is more remote from the surface than the imaginary focus L , and the distances KM and LM will be in the ratio mentioned in §. 886. Therefore these rays become less converging.

§. 890. If the parallel rays AB , CD , fall upon the plain superficies BD of a medium of a different density, whether greater or less, after refraction they will continue to be parallel. In a denser medium they will proceed according to BE and DF , in a rarer medium according to BG and DH . For the rays AB and DC will undergo an equal refraction, and therefore the angle $ZDF = ZBE$, or $RBG = RDH$, and therefore BE and DF , as also BG and DH , are parallel. Tab. 11.
Fig. 14.

§. 891. Let Z be the superficies of a denser medium, AB a convex spherical surface, upon which let the rays CA and BD fall, which are parallel and near to one another, out of the rarer medium, which being refracted let them meet in the focus G . Then will GB , the distance of the focus from the superficies, be to FB , the radius of the sphere, as the sine of the angle of incidence is to the sine of the difference between the angle of incidence and of refraction. Let the right line DB fall perpendicularly; this without refraction Tab. 11.
Fig. 15.

fraction will pass directly through the center F. From the center F the right line FAE being drawn, the angle of incidence for the other ray CA will be equal to CAE, to which AFB is equal. This external angle is equal to the two internal angles of the triangle GAF and FGA. But GAF is the angle of refraction, and therefore the angle FGA is the difference between the angles GAF and AFB. But GF is the sine of the angle GAF. Now by §. 876. the sine of the angle AFB is to the sine of the angle AGF as GA to FA, or as GB to FB. And therefore GB is to FB as the sine of the angle of incidence to the sine of the angle of the difference between the angles of incidence and refraction.

Tab. II.
Fig. 15.

§. 892. Let the diverging rays DB and DA fall upon the same spherical superficies AB. Now because the angle of incidence DAE is greater than in §. 891. also the angle of refraction FAH will be greater; and therefore the distance of the focus H from the superficies AB is also greater. But that the point H may be found, imagine parallel rays proceeding from the contrary part Z to have their focus in Y. With radius FY describe the arch Yp, then draw AH parallel to the right line Fp, and H will be the point required. For if p be a radiating point, pF passes strait on, and pA falls upon a very near point, whence it necessarily follows, that the ray moves in a parallel manner to pF. But pA comes as it were from DA. The triangles DpF and DAH are similar. Therefore $Dp : pF :: DA : AH$. Or $DY : YF :: DB : BH$. Hence arises another rule; since it is $DY : DY + YF :: DB : DB + BH$. And by permutation, $DY : DB :: DF : DH$. But the nearer the radiating point D shall approach to the superficies AB, the much

much the more the angle of incidence increases, and therefore the angle of refraction also. Now if this be made equal to AFB , the refracted ray AL will be parallel to BH . If the radiating point D approaches nearer to AB , the angle of refraction will become greater than the angle AFB , so that the rays will continue diverging after refraction, though less diverging than at their incidence.

§. 893. The converging rays EA and DB may fall upon the superficies AB with directions tending to the center F . These falling perpendicularly in A and B , will pass to the center F without any refraction.

§. 894. If the incident rays converge less, as MA and DB ; the angle of incidence MAE will be less than of the parallel ray CA . Wherefore the angle of refraction FAI will be less than the refracted angle of the parallel FAG , and the distance IB will be less than GB , the point I approaching so much the nearer to F , as the ray MA approaches nearer to EA .

§. 895. If KA be the incident ray, after refraction this will converge less, because it approaches to the perpendicular AF , and falls in some point S , between F and B ; but it is so much nearer the center F as KA is nearer to EA .

§. 896. From all these things in §. 891. 892. 893. 894. 895. the contrary course of the rays is easily deduced, when they pass out of a denser medium into a rarer, and fall upon a concave spherical surface AB . For if the diverging rays SB and SA fall upon AB , then BD , AK , will be the refracted rays.

If diverging rays proceed from the center F , they will pass without refraction, because they fall perpendicularly.

If

If the radiating point shall be between F and G, the refracted rays will be BD, AM.

If the radiating point is in G, the refracted rays AC, BD, will be parallel. If the radiating point be placed beyond G, as in H, the refracted rays will meet in D. If the incident rays HB, LA, are parallel, the refracted rays will meet nearer the superficies AB than before; and the distance FD of the focus D from the centre F, will be to FB the radius of the sphere, as the sine of the angle of incidence, to the sine of the difference between the angles of incidence and refraction. For the angle of incidence is $\angle LAF = \angle EAC$, the angle of refraction is $\angle EAD$, the difference of the angles $\angle EAC$ and $\angle EAD$ is the angle $\angle CAD = \angle ADF$. The sine of the angle CAE or of $\angle FAL$, is FD; and the sine of the angle ADF is $AF = FB$. Therefore the sine of the angle $\angle LAF$ is to the sine of the angle $\angle CAD$, as FD to FB. If the incident rays are converging, the refracted rays will meet sooner.

Tab. 11.
Fig. 16.

§. 897. Let there be a convex spherical superficies AB, let the denser medium X be on the convex side, and the rarer medium Z on the concave side; let the rays DB, CA, fall parallel, of which DB falling perpendicularly, passes through the centre F without refraction. Then drawing FAE perpendicularly at the place of incidence A, CAE will be the angle of incidence. Now because by refraction the ray will be obliged to recede farther from the perpendicular FA, it will take the course AG, and therefore the parallel rays will diverge from one another after refraction. Let the ray GA be drawn backwards, till it meets with the other in S, which is the imaginary focus. The angle of refraction is $\angle GAF = \angle EAS$, and therefore $\angle CAS$ is the difference

ference between the angles of incidence and refraction, to which the angle ASF is equal. Wherefore the sine of this angle to radius AF , as the sine of the angle of refraction EAS , to which the sine of the angle FAS is equal, to FS the distance of the centre of the spherical surface from the imaginary focus S .

§. 898. If the diverging rays DB , DA , fall upon the same convex spherical superficies AB , after refraction they will diverge from one another more than parallel rays: for because the angle of incidence DAE is greater than CAE , therefore the ray DA when refracted becomes AH . If this be continued backwards, it will meet with the axis in K , which point is the imaginary focus, and is thus discovered. DAE is the angle of incidence, HAF that of refraction, to which EAK is equal; and therefore DAK is the difference between the two angles. AKF is the external angle of the triangle ADK , equal to $KAD + KDA$, which are known. Therefore in the triangle FAK , the sine of the angle AKF is to the radius FA , as the sine of the angle FAK , or KAE , is to FK , the interval between the centre F , and the imaginary focus K . Now by how much the more the radiating point D is remote from the superficies AB , so much the more the angle of incidence DAE decreases, till it becomes nearly equal to the angle CAE . And by how much the more the point D approaches nearer to AB , so much the more the angle of incidence DAE increases, and also the angle of refraction, and so much the more the refracted rays diverge from one another. Wherefore the imaginary focus will continually approach to the superficies AB .

A

If

If the converging rays DB , EA , fall upon the same superficies AB , and which produced would meet in the centre F , these falling perpendicularly upon AB , will pass without refraction to F . But if any fall that converge but little, as DB , QA , because by refraction they recede more from the perpendicular AF , they will become either less converging, as BR , AR , or parallel, as BR , AM . For let QA be continued to R , and the angle QAE will be equal to RAF . If now the sine of the angle RAF is to the sine of the angle MAF , as the sine of the angle of incidence is to the sine of the angle of refraction, then the ray QA after refraction will proceed in the line MA parallel to BR . And the angle QAE decreasing, RAF and MAF will decrease. Therefore the ray QA after refraction will concur with BR . But incident rays that converge more, as DB , PA , by receding more from the perpendicular AF become more converging. For the course of the ray PA is AO .

§. 899. Now we may easily know the course of such rays as return back out of a rarer medium Z into a denser X , when they fall upon a concave spherical surface AB . For the parallel rays RB , MA , after refraction become diverging BD , AQ .

Diverging rays FA , FB , emitted from the centre F , without refraction proceed in the paths FAE , FBD .

Diverging rays RB , RA , emitted from a radiating point beyond the centre F , after refraction diverge more from one another, since they approach nearer to the perpendicular AE .

Diverging rays OB , OA , emitted from a radiating point O , between the centre F and the superficies

superficies AB , being refracted become less diverging, since they approach nearer to AE .

Converging rays RB , GA , being refracted become less converging, or parallel.

C H A P. XXX.

Of light passing out of air into glass, and thence again passing into air.

§. 900. **L**ET $ABCD$ be a piece of glass, Tab. 12.
terminated by the plain and parallel Fig. 1.
superficies AB , DC , upon which out of air let the oblique ray EF fall, which is there refracted. By refraction this will approach to GFO drawn perpendicular, and will proceed in FL , and therefore falling obliquely at L , being again refracted it will pass out of the glass into the air, in the path LN receding from the perpendicular RLP . Now because the sine of the refracted angle LFO is to the sine of incidence GFE , as 11 to 17; the angle FLP will be equal to LFO , and the sine of the angle FLP will be to that of RLN , as 11 to 17. Then the angle RLN will be equal to EFG , and therefore the incident ray EF is parallel to the ray LN , passing out of the glass into the air.

§. 901. Let ABC be a glass prism, on whose Tab. 12.
superficies AB let an oblique ray HF fall out of Fig. 2.
air, which being refracted will approach towards the perpendicular FP in the path FS . This ray falling obliquely in S , when it goes out into air will be refracted in the path SM , by receding from the perpendicular QSO . The ray DK falling perpendicularly on AB , passes strait to I without refraction; but since it strikes upon AC obliquely, going out of the glass into the air, being

ing refracted from the perpendicular IN , it proceeds in the path IR .

Spheres and various segments of spheres are made of glass: first, such as are plain on one side, and convex on the other. Secondly, convex on both sides. Thirdly, plain on one side, and concave on the other. Fourthly, concave on both sides. Fifthly, convex on one side, and concave on the other, of different radii.

§. 902. These spherical segments, Tab. 12. Fig. 9, 10, 11, 12, are called *Lenses*. But Tab. 12. Fig. 7. this species is called *Meniscus*, or Fig. 8. a concavo-convex.

§. 903. A right line passing through the centre of the sphere, and perpendicular to the other plain surface; or passing through the centres of the two spheres, is called the *Axis*.

Tab. 12.
Fig. 3, 4.

§. 904. If parallel rays fall upon a sphere, which is either denser or rarer than the ambient medium, and in the diameter produced, which is parallel to the incident rays, the point T is the focus of the first refraction in the superficies AC ; then the point F , in the middle between D and T , will be the focus of the refracted and proceeding rays.

For let the incident and proceeding rays QA , FG , produced meet one another in H . Because the refraction in the points A and G is equal, the triangle AHG will be isosceles. And since the angle GTF is equal to HAT , and HGA equal to TGF , the triangle GFT will also be isosceles. If now the ray QA be very near the diameter CT , the right line $GF = DF = TF$. Therefore the focus F is in the middle between D and T .

§. 905. There is a certain point E in lenses that are convex or concave on both sides, through which

which any ray passing, as well incident as QA , as proceeding as aq , which remains parallel to itself. But in a lens that is plano-convex, or plano-concave, the point E lies in the vertex of the convex or concave superficies; and in a double meniscus E lies without that surface that has the greatest curvity.

Let REr be the axis of the lens, joining the centres R, r , of the surfaces A, a . Let there be drawn two semidiameters RA, ra , parallel to each other, and let the points A, a , be joined. Then the line Aa will cut the axis in the point E . For since the triangles REA, rEa , are similar, it will be $RE, Er :: RA, ra$; and therefore the point E cannot be changed in the same lens. Let us now suppose the ray to recede on both sides from Aa , which is equally inclined to the perpendiculars on both surfaces, and therefore the ray must be inflected on both sides, with a contrary direction, so that AQ may be parallel to aq . But if the lens becomes plano-convex, or plano-concave, some semidiameter RA or ra will become infinite, and therefore parallel to the axis of the lens; and then the other semidiameter will coincide with the axis, and so the points A, E , or a, E will coincide.

Tab. 12.
Fig. 5, 6,
7, 8.

§. 906. But the point E , which is called the *Centre of the Lens*, may be thus determined. In the like triangles $RAE, r a E$, it is $RA, ra :: EA, Ea$. And *dividendo* 'tis $RA - ra, ra :: EA - Ea$. or $Rr. Aa :: ra. Ea$. That is, the difference of the semidiameters is to the thickness of the lens, as the lesser semidiameter to the distance of the point E from the greater curvity.

§. 907. If therefore a pencil of rays shall fall almost perpendicularly upon any lens of a very small thickness, the rays passing through the

VOL. II.

G

point

point E may be taken for a right line drawn through the center of the lens, without any sensible error.

§. 908. The focus of parallel rays, that fall almost perpendicularly upon the lens, may be thus found.

Tab. 12.
Fig. 9, 10,
11, 12,
13.

Let E be the center of the lens, R, r, the centers of the superficies, R r the axis, g E G a line parallel to the rays incident upon the superficies B, whose center is R. Let the semidiameter B R be drawn parallel to E g, in which produced let V be the focus of the rays that are refracted by the superficies B alone. Draw V r cutting g E protracted in G, which will be the focus of the rays issuing out of the lens. For because V is the focus of the rays refracted by the superficies B, the rays will fall with an oblique direction B V upon the superficies A, and therefore the rays issuing from A must necessarily have their focus in some point of that ray, which passes strait through this superficies A, that is in the line V r drawn through the center r. And because the ray passing through the point E may be esteemed as a right line, which let be g E G, the point G of it's intersection by V r will be the focus of all the rays.

§. 909. If the rays incident at the axis R r are parallel, the distance of the focus E F is equal to E G. For let the incident rays, parallel to g E, be gradually more inclined to the axis, till they become parallel; then their first and second foci V and G will describe the arches V T and G F, the centers of which are R and E. For the line RV is immutable, having to R B the ratio of the sine of refraction to the sine of the difference between the incidence and refraction, by §. 891. And therefore E G is invariable, and

to

to the line RV in the ratio of rE to rR ; because the triangles EGr and RVr are similar.

§. 910. If the lens consists of a thin glass, the focus may be thus found from the preceding proposition. Since in the similar triangles EGr and RVr it is $GE.VR :: Er.Rr$ and VR becomes TR , and GE becomes FE ; it will be $Rr.Er :: TR.FE$. Or the distance of the centers of both the curve superficies, is to the distance of the lens from the center of either of the curve superficies, as the semidiameter produced to the focus of the first superficies, is to the distance of the focus from the lens.

§. 911. If therefore the lens be concave or convex on both sides, it is as the sum of the semidiameters to either of the semidiameters, so is the double of the other semidiameter, to the distance of the focus from the lens. For $RT = 2RE$, as also $rt = 2er$, and therefore $Et.tr :: 3.2$.

§. 912. But in a meniscus it is, as the difference of the semidiameters to either of the semidiameters, so is the double of the other, to the distance of the focus from the meniscus.

§. 913. If the semidiameters of both the curve superficies shall be equal, the focal distance will be equal to one of the semidiameters: but in a plano-convex lens, or plano-concave, the plain superficies will have (as it were) an infinite semidiameter. Whence the ratio of Rr to Er is a ratio of equality. So that also TR to FE is in a ratio of equality, or $TR = FE$. And because TR to RE is as the sine of the angle of incidence to the sine of the difference, FE to RE will be in the same ratio.

§. 914. Let Q be the radiating point, from Tab. 13. whence diverging rays are transmitted to the lens Fig. 1, 2.

or sphere, whose center is E. If then parallel rays had proceeded from the other side of the lens, whose focus let be F, by §. 908; and in the axis QE produced were taken QF. $FE :: Ef.fq$; the point q would be the focus of the refracted rays, if the radiating point Q were not much distant from the axis of the lens.

For center E, and Radii EF, Ef, let two arches be described FG, fg, cutting the ray QAaq in G and g, and let EG and Eg be drawn. Let G be supposed to be the focus of the incident ray GA, the issuing ray will be agq, parallel to GE, by §. 908. So on the other side let g be supposed to be the radiating point, and ga the incident ray, then the issuing ray will be AGQ parallel to gE. Therefore the two triangles QGE and E g q will be similar, and it will be $QG.GE :: Eg.gq$. If therefore the ray QAaq be very near the axis QE q, it will be $QF.FE :: Ef.fq$.

It is also $QG.GE :: QA.Aq$, or $QF.FE :: QE.Eq$. It is also $QG.QA :: QE.Qq$, or $QF.QE :: QE.Qq$.

If Q approaches towards F, and coincides with it, the issuing rays will be parallel: For then q goes on to an infinite distance. If Q approaches to the lens beyond F, then the focus q passes to the contrary side of the lens.

C H A P. XXX.

*Of the different refrangibility of the rays of light,
and of colours.*

§. 915. **W**HAT has hitherto been observed of the rays of light, is built upon the supposition, that all rays are of the same degree of refrangibility; which indeed is not true in fact. For the great *Newton* has discovered, that a ray of light emitted from the sun, such as we are concerned with, is a collection of small rays which are endued with different refrangibility. Thus if a ray OF emitted from the sun, shall fall obliquely upon the superficies EFG of a denser medium, it would not only be refracted to FR, but would split into little rays FT, FS, FR, FQ, FP, which by diverging from one another, shew that the Ray FP is more refracted than FT.

Tab. 13.
Fig. 4.

§. 916. That the experiments may be better understood, by which this wonderful property of light is to be proved, some things are to be here premised. If a ray of the sun is made to enter into a dark place, through a small hole, it is enlarged, and being received upon a plain directly opposite to it, it illuminates a circular space, which will be so much the greater as the plain is farther distant from the hole: because rays from the whole hemisphere of the sun pass through the hole, and intersect one another in an angle, equal to the apparent diameter of the sun. This being observed, let a large and deep vessel be taken, at the bottom of which (if it be transparent it is so much the better) a ray of the sun may be received as it

passes through the hole, and the length and breadth of this circular image may be observed; then let the vessel be filled with water, and the length of the illuminated circle at the bottom will be enlarged, but not the breadth.

Tab. 13. §. 917. Or let there be taken a rod of glass
Fig. 5. with three angles like a wedge, ACB , which now is called a *glass prism*, whose solid angles may be each of 60 degrees, upon which, through the hole FZ , let a ray of the sun fall $OFXZ$, which being refracted, and received upon a white plain at the distance of some feet, will exhibit an oblong image, whose breadth IC is but about one fourth part of it's length. It's breadth IC is the same, as if at a like distance from the hole F no prism had been interposed. This oblong image is composed of many circles falling upon one another, some of which are represented by GPA , HB , IC , KD , LTE , which having all the same diameter cause the image at the sides to appear terminated by right lines GL , AC , parallel to one another, and at the ends P , T , by equal semicircles. Every circle represents the image of the sun; therefore among these there are some, whose rays are refracted more, and others less, by the prism.

Tab. 13. §. 918. If at the distance of 10 or 12 feet
Fig. 6. from the window, we look through the prism ABC upon the round hole FZ , in the place PT it will appear oblong, like the former image: a sure token that the rays PH are more refracted than TI .

§. 919. The ray SF is refracted by the prism ABC into the oblong image PT , which was projected upon another prism KM , that it might be examined, whether the rays now refracted would be dilated as before, and would then acquire

quire a square figure $pqt\pi$, but this did not happen; the former image PT only acquired an oblique situation pt , which was composed of the same circles. The rays which were mostly refracted in the first refraction were again most refracted in the second refraction. By which it came to pass, that in both the images compared, p, P , were farther distant from one another than T, t ; that is, the radii P, p , were most of all refracted, and T, t , less refracted. Tab. 14.
Fig. 1.

§. 920. Therefore the ray of light, as it is transmitted from the sun to us, consists of light which is very *heterogeneous*, since it is subject to such a different refrangibility. Now that which contains light that is alike refrangible, Philosophers call *homogeneous*.

§. 921. If we view a ray of the sun's light directly, or receive it upon a smooth white paper, it appears of a bright whiteness.

§. 922. A ray of this kind, passing through a glass prism and thereby refracted, then received upon a white plain, exhibits an oblong spectrum PT , variegated with a great diversity of colours, which are disposed in such an order, as that these following are chiefly distinguished, red, orange, yellow, green, blue, purple, and violet. Tab. 13.
Fig. 5. But in each class of colours there are many intermediate ones, because they are not intirely distinct, but interfere with one another at the sides. If you conceive the whole spectrum to be divided into 360 parts, every colour takes up so many of these parts in it's length, as the number at the side declares. Tab. 14.
Fig. 2.

§. 923. Of the coloured rays the red are least refracted, and the violet most. Other intermediate colours are so much the more refracted as they recede from the red to the violet, as we may

be informed by a view of the rays going out of the prism.

Tab. 14.
Fig. 3.

§. 924. Or if a plain CI, painted with two colours, cinnabar and indigo, be looked upon through the prism in two manners, by an eye placed at K; it will be seen at D divided into two parts C and I. If the prism be turned into the situation B, the object will appear again divided at E, as C and I. Now since both the images C, C, of the cinnabar, seem nearer to one another, and those I, I, of the indigo colour are farther removed from one another, it is plain that the red rays are less refracted than the violet.

Tab. 14.
Fig. 4.

§. 925. If the same object painted with both the colours be illuminated with the light of a candle, after the manner of Dr. *Desaguliers*^a, and let a large lens LL collect the rays; the red ones have their focus P more remote from the lens in the plain S, the blue ones nearer O in the plain B: A further proof that the blue ones are more refracted than the red ones.

Tab. 14.
Fig. 5.

§. 926. The refrangibility continues always the same in the same colour, so that the red rays being several times refracted, still are less refracted than the violet rays, or others of intermediate colours. Let S be the sun, whose ray transmitted through the whole F may fall upon the prism ABC, which may refract it into its colours, which are received upon the plain DGE; this being perforated, let it transmit one colour upon the board $\delta \gamma \eta$, which also having a hole, let it transmit a colour upon another prism abc; this being refracted a second time, let it proceed to M. The first prism ABC being turned about its

^a Phil. Transf. N. 426.

axis, all the colours may be projected successively upon the other prism abc , which being refracted will again be observed between M and N , though all now come with the same incidence to the prism abc ; yet the violet rays are found to be more refracted than the red ones in this second refraction.

§. 927. Because the red rays are refracted less than the rays of other colours, they keep their way more obstinately, and are less liable to be diverted from it by the attracting and refracting force; and therefore the particles that compose the red rays are moved with greater force, and will be either greater or more dense than the particles of other colours. It is probable, that in a sun-beam, consisting of all colours, the red particles move with the same velocity as those of other colours; therefore a greater power must be in them, either supposing an equal density but a greater volume, or a greater density under the same volume.

§. 928. We may also conclude, that there is a greater force in the red rays, from the glaring with which they strike the eyes; for the red rays shine very brightly, whereas the violet ones can hardly be seen, because they affect the sight but weakly: but the green rays, affecting the eyes moderately, are pleasing to them, since they move them neither too strongly nor too weakly.

§. 929. The colour that is found in any ray separated from the rest, always continues invariably the same, however this ray may be refracted through glasses, prisms, or lenses; or whether it is condensed into a focus by means of lenses, or is reflected by any speculum, or by any other body, and is then viewed through a prism. A red ray for instance always exhibits redness, and never any other

other colour ; a green ray always retains it's greenness, and the same obtains in other colours.

§. 930. So that the difference of motion or gyration of the several parts of light, arising from the refraction, is not the cause of the difference of colours. For this gyration would be changed as soon as the light was refracted a second time, or reflected, or collected ; so that from a coloured ray different colours would again arise, which never happens. Therefore it is owing to their own nature and constitution, that some rays excite a sensation of one colour in the mind, and other rays a sensation of another, while the constitution of the ray continues the same, every one will constantly exhibit the same colour. But I would here have it observed, when I speak of the colour of rays, that it is not my opinion that such colours are in the rays themselves ; but that they have only a certain power so to move the nerves of our eyes, that their motions may excite in our minds the idea of colours. The rays to which the idea of a red colour is annexed, I have called red rays, and so of the yellow, green, violet, &c. as if these colours were really in the rays, because they appear thus to such as behold the experiments.

§. 931. A collection of all the coloured rays into one place constitutes brightness, or white.

Tab. 14.
Fig. 6.

For if by means of the prism *A B C* a ray of the sun is refracted into it's coloured pencils, which falling upon the convex lens *M N* are refracted, and then collected in the focus *G* ; this focus being received upon a white plain *DE*, will appear white. Now that in this focus there is only a mixture, and not a destruction of the colours, will appear from hence. If the plane be moved beyond the focus, the colours will presently appear again, but in an inverted order.

§. 932.

§. 932. If the focus G be viewed, by means of another prism HIK , it appears refracted into it's colours; as the red in r , the violet in v , with the other intermediate colours.

§. 933. Let two prisms ABC , abc , having equal refracting angles B and b , be placed parallel to each other, so that the angle of the prism B may touch the other c , and the two sides CB and cb may lie directly to one another; let the light passing through those prisms be received upon a paper MN , which may be distant from the prisms about 8 or 12 inches: now the colours produced by the inward extremities B and c of the two prisms will be mixed in the place PT , and there will exhibit whiteness. For if either of the prisms be removed, the colours produced by the other will appear in that place PT . Tab. 14.
Fig. 7.

§. 934. If paints of very different colours be mingled with one another in a determinate proportion, as orpiment, verdegrease, mountain-blue, purple, they will produce a powder, which dawbed pretty thick upon paper, and viewed at the distance of 18 feet, will appear as white as paper.

§. 935. If the rays of all the colours are not mingled, whiteness will not be produced; but it will recede the more from this, and incline more to a wan, or some other particular colour, the more the coloured rays are intercepted, and the fewer colours are united. For if the light refracted by the prism into it's coloured rays, shall fall upon the lens MN , and G the focus of all the colours be white, at T let some one of the colours be intercepted, suppose the violet; then the focus G will no longer be white, but will incline to a brown. Again the indigo being intercepted, G will be still less white; and Tab. 14.
Fig. 6.

and the red being stop'd at P, the focus G will be yellow and green. Lastly, the green being stop'd, the focus G will be perfect yellow.

§. 936. If the beams of the sun be refracted by the prism into it's colours, and some coloured ray fall separately upon an object tinged with paint, that object will appear of the colour of the incident ray, and not of the colour of the paint. But if the colour of the incident ray be the same as that of the paint, the colour of the painted object will become very lively; whereas if it be illuminated with any other colour it will be much more obscure. From whence it appears, that coloured objects by reflecting the rays of light do not change their colour, but that these objects reflect some of the coloured rays more copiously, and others in less quantity.

§. 937. Hence it appears why objects appear of a bluish colour, in a place where spirit of wine is burning. Also why coloured objects by candle-light appear of a different colour from the same viewed in the sun-shine, moon-shine, or by the light of a lamp. For by a candle yellow paper appears more languid, the colour inclining to a pale straw-colour. Things painted with deep green appear bluish; when looked upon together with a bluish object, it appears greenish; compared with yellow it seems more blue. More of these appearances are mentioned by the noble *Boyle*, in his treatise of colours. Because no black rays are exhibited by the prism, we may conclude black to be no colour; as also because the deeper shadows, and other like things, or objects that reflect but little light, appear black.

§. 938. As often as light falls upon thin transparent plates, it is also separated into colours, of which some are reflected, and others transmitted, according

according to the different thickness of the plates. This is observed manifestly, when we put two object-glasses of long telescopes upon one another; for the air lies between them like a thin plate, but of a different thickness. It is thinnest where the glasses touch, and thicker afterwards, as the distance is greater from the point of contact. Let the light fall upon the upper lens, and let us view it from above; then where the glasses touch there appears a black spot; then several rings separate from one another surround this, the colours of which, beginning at the center, are disposed in the following order. Tab. 14.
Fig. 8.

Black, blue, white, yellow, red.

Violet, blue, green, yellow, red.

Purple, blue, green, yellow, red.

Green, red.

There are others, which are so much the weaker, as they are farther distant from the center. These are produced by reflexion from the air between the glasses.

§. 939. If we view the lenses on the other side, so that the rays when transmitted may fall upon the eye, the coloured rings appear again, but in those places in which the foregoing rings were distant from one another. The orders, beginning from the middle, are thus.

White, red, yellowish, black, violet, blue.

White, yellow, red, violet, blue.

Green, yellow, red, bluish-green.

Red, bluish-green, &c.

§. 940. All these things are perceived also in bubbles, which are formed by blowing into water impregnated with soap. For as in a little time these bubbles become thinner, the water descending from the upper part to the lower, we may observe

observe just such coloured rings to arise, and indeed in different parts of the bubbles, as some parts become thinner and others thicker; and these are made by the reflexion and transmission of the light, as before in the lenses.

§. 941. Paints and painted objects have properly no colours, but break the light that falls upon their surfaces into colours, of which they reflect some, and absorb others, which after many internal repercussions they either suffocate or transmit; wherefore objects are seen under that colour, which belongs to the reflected rays of light. Paints are very fine corpuscles, and therefore are to be esteemed as the thin plates mentioned §. 938. which reflect a different colour, according to their various thickness. Therefore the same paint, according to the different grossness of its parts, will be seen of different colours. Cinnabar when in a lump how little is it red? Being beaten into powder of a moderate fineness exhibits a most beautiful red: when beaten upon a porphyry-stone into an impalpable subtilty, with water, it loses much of the beauty of its colour, and approaches towards orange; but a most beautiful redness returns, by putting to it linseed oil, or that of poppy or turpentine. A like thing is observed of verdegrease. And hence also it is manifest, that if the superficies of some bodies is changed, either for a rougher or smoother, because of the compression of the parts to one another, and therefore because of some kind of increase they undergo, the bodies will appear to be coloured otherwise than they were before. Paper that is rough appears much whiter than that which is smooth. Silver when rough is very white, but when polished it grows black.

§. 942.

§. 942. Also if we consider the light that passes through thin plates, as in §. 938 and 939, we shall learn the reason why, if coloured objects are transparent, they appear of one colour when seen by means of reflected light, and of another by transmitted light. Is it not very plain, when we look upon the feathers of birds, and especially those of the necks of pigeons, that being inflected by various motions they exhibit most beautiful colours, some of which are owing to reflexion, and others to transmission. This is also conspicuous in an infusion of *lignum nephriticum*, which appears of several colours, according to the different situation both of the eye and the light. It is so likewise with some silken garments; as also with very thin plates of gold set before a microscope, through the pores of which the blue light only passes.

§. 943. Also the tinctures of some bodies, that shew different colours by putting to them different solutions, and losing them again return to their former state, afford agreeable amusement. As if to the tincture of red roses with spirit of wine, which is yet whitish, an acid saline spirit is added, as spirit of vitriol, oil of sulphur, spirit of sea-salt or of nitre, aqua fortis, though in so small a quantity as that the acid can hardly be perceived, it will be changed into an elegant tincture of the colour of red roses. But if to the same tincture of roses be poured a solution of alkaline salt, it will be changed into a green tincture; as is also done by putting in oil of tartar per deliquium, or spirit of sal ammoniac. But if to the same tincture of roses be added the white solution of vitriol of Mars in water, a black ink will be produced: If to the former red tincture, because of the acid spirit put to it, you add

add a solution of alkaline salt, the redness will be changed into a green colour ; and if to the green colour, because of the alkaline salt, you add an acid spirit, it will be changed into a ruddy tincture.

If to a transparent solution of galls be added common vitriol of Mars, either calcined till it is white, or to the form of red colcothar, it immediately grows black ; but the blackness will vanish by pouring in some drops of oil of vitriol, and it's former transparency will return. Put to this liquor some oil of tartar *per deliquium*, and the blackness will return again, but will be lost again by the affusion of an acid spirit. The great *Boerhaave* ^a has supplied us with many other things of a like nature, and some are to be found in the *Florentine* essays ^b, as also in *Hellsbam* ^c. This production and change of colours depends on the various magnitudes of the particles floating in the solution, which are sometimes bigger and sometimes less. For that these colours arise from thence has been very ingeniously proved by the great *Newton* ^d, who has almost exhausted this doctrine of light and colours, and has improved it with many other discoveries, which we cannot enlarge on in these institutions.

^a Chem. Vol. 2. p. 535.

^b Part. 2. p. 93, & seq.

^c Lectures, c. 20.

^d Opticæ Lib. 2. part. 2.

C H A P. XXXII.

A description of the Eye.

§. 943. **H**OW objects placed without are seen by us, cannot be explained, unless the structure of the eye, which is the organ of vision, be first understood. Wherefore I shall endeavour to describe it in the shortest manner I can. We have received from nature two eyes, placed in the middle of the face aloft in the head, that they may be near the brain; each of them lies deep in a bony socket, which is accurately described by the learned *Winslow*^a, and in which it is safe guarded from injuries, that might happen either from behind, or sideways. It is something prominent out of this socket, and is defended before by two eye-lids.

§. 944. Above the upper eye-lid, and at the lower part of the forehead, is placed the eye-brow, composed of very many arched short hairs, very thick at the greater *canthus*, but thinner at the lesser, that run from the greater to the lesser *canthus*. These hairs hardly ever fall, are conical, something hollow within, and full of pith. The eye-brow is raised, depressed, brought towards the nose, made smooth, or wrinkled, by the muscular fibres of the forehead^b, as also by those which raise the pins of the nose. By these hairs are intercepted any dust, filth, sweat, which slipping down the forehead might otherwise fall into the eyes, and obstruct the sight. Also the hairs being depressed, prevent too much light coming from above the eye.

^a L'Hist. de l'Acad. Roy. An. 1721.

^b Eustach. Tab. 41. Fig. 1.

§. 945. The eye-lids are two membranaceous defences before the eyes, of which one is above and the other below ; as by coming together they shut the eye, so by separating they discover it again. They are very thin, that they may be something transparent, yet they consist of an epidermis, a skin, a cellulous membrane, a muscle, and a very smooth inward membrane full of vessels, and perforated with very many *oscula* of excretory ducts, taking their rise from little glands. The limbs of the eye-lids are cartilaginous and very smooth, perforated with ducts^a, through which a waxy matter exsudes, that they may not be dried up by the air, nor the tears pass through, nor the eye-lids stick together. The upper eye-lid is raised by the attolent muscle^b, and is let down by the depriment^c. The eye-lids do not only defend the eyes from external injuries, but also by their aperture adjust the quantity of light, that it may not hurt the very tender retina, when we look upon objects that are strongly illuminated. Also they continually wash away all filth, when our eyes twinkle, and they moisten the cornea and preserve it's transparency.

§. 946. At the utmost external margin of the eye-lids there is a row of hairs, which is called the eye-lashes, standing out almost strait, in the upper eye-lid bent upwards, and downwards in the lower, that they may not hinder the entrance of the light. They are of a like structure to that of the eye-brows, and defend the eye against external filth, or the approach of little animals.

^a Bartholin. Anat. L. 3. Tab. 10. Fig. 8.

^b Eustach. Tab. 41. Fig. 1.

^c Verheyen. Tab. 27. Fig. 1.

§. 947. At the greater *canthus* of the eye, on the inward margin of each eye-lid, is seen a little hole, as it were the middle of a prominent papilla, which is called the *punctum lachrymale*. Each is the orifice of a vessel that runs towards the nose, near which both being conjoined form the *saccus lachrymalis*, emptying itself through a canal into the nostrils^a. These points by attraction absorb the tears into themselves, in the same manner as water is attracted in capillary tubes. And as this apparatus is analogous to a capillary siphon with unequal legs, the tears attracted by the points will flow in the same manner out of the longer leg, which inheres in the nostrils.

§. 948. At the greater *canthus* is the *caruncula lachrymalis*, which is red, rough, spongy, between the two eye-lids, hindring lest the eye-lids should first be shut here, opposing the tears which are determined hither, that they may the more easily be absorbed by the lachrymal points.

§. 949. The great gland, placed between the ball of the eye and the upper eye-lid, in a good deal of fat, is extended from the lesser to the greater canthus, and sends forth ducts which run obliquely between the fat and the internal membrane of the eye-lid^b, out of which a liquor called tears is perpetually poured, intended for watering and washing the cornea.

§. 950. The ball is composed of some of the tunics of the eye, the first of which is the *adnata*, and constitutes whatever is in the eye that outwardly appears white, when the eye-lids are open. It is membranaceous, very thin, nervous, white, brought over the fore part of the eye and

^a Drake Anthrop. Tab. 17. Fig. 6.

^b Verheyen, Tab. 27. Fig. 3.

over the cornea by the quantity of $\frac{1}{3}$ or $\frac{1}{2}$ and sometimes a whole line. This does not enter the bony socket, but by extending itself every way it joins the ball to the *periosteum*, and keeps it fast, that it cannot fall out of the socket. Thence bending backwards, it constitutes the internal superficies of the eye-lids.

§. 951. The eye lyes buried on all sides in a soft bed of fat; and with this it's muscles are perpetually anointed and lubricated, that they may perform all their motions with ease and expedition. They are performed by means of the four *musculi recti*, and the two obliqui, which are very well described by *Eustachius*^a, and *Winslow*^b. These move the eye according to all directions, may bring it something forward out of the socket. They receive nerves from the pairs called motory, pathetick, the fifth and sixth, and from the intercostal^c.

§. 952. The ball of the eye would be a perfect globe, if it were not for the fore part, where the cornea is, and where it is a little protuberant; and on the back part it adheres to the optick nerve. The eye of an adult person from the cornea to the optick nerve is $11\frac{1}{3}$ lines long, *Paris* measure.

§. 953. The outward membrane that covers the whole ball of the eye arises from the dura mater in the brain, which involves the optick nerve that enters through a hole in the bony socket, where coming to the eye it is extended into a sphere. When it comes to the fore part, it grows thin, becomes more flexible, less leathery, is transparent, and more protuberant. While it continues opake it is called *tunica sclerotica*; when

^a Tab. 29. Fig. 2, 3, 4, 5.

^b L'Hist. de l'Acad. Roy. An. 1721.

^c L'Hist. de l'Acad. Roy. An. 1726.

it becomes transparent it is called the *cornea*. It is composed of many folds upon one another. The *sclerotica* is not so thick under the *musculi recti* as in the other part of the eye. The *cornea* is a segment of a sphere, whose diameter is generally 7 or $7\frac{1}{4}$ or $7\frac{1}{2}$ lines. Its chord is either 5, $5\frac{1}{4}$, or $5\frac{1}{2}$ lines. The thickness of the membrane is commonly $\frac{3}{4}$ or $\frac{3}{8}$ of a line, as Mr. *Petit* has observed^a. On the outside it is perforated by *vascula*, from whence a humour is derived, according to *Steno* and *Winslow*. Out of these a thick viscid liquor flows, when the sphincters are relaxed in agonizing people.

§. 954. Under the former lies a second membrane, arising from the *pia mater* in the brain, that surrounds the optick nerve, and then the bulb of the eye. This is double. The external one is contiguous to the *sclerotica*, and is called *choroeides* or *uvea*; and where it is distant from the *cornea* it is called *iris*. The inward membrane is the *ruyschiana*, which bending inwards near the *iris*, covers the vitreous and crystalline humour. The *iris* is perfectly round, and pierced with a round hole, which is called the *pupil*. This is not exactly in the middle of the *iris*, but nearer the nose. The *iris* is tinged with various colours, and is composed of muscular fibres, tending from the external ambit to the center, and terminated in the orbicular limb. This limb is also provided with muscular fibres, like a sphincter, determining the figure of the *pupil*. These are connected with the former, and also with small pellucid membranes. The longitudinal muscles dilate the *pupil*, which is contracted by the orbicular, so that the *pupil* seems capable of being

^a L'Hist. de l'Acad. Royal. An. 1728.

dilated, especially in infants, but less in old men. The intention of which is, that we might receive more of the light transmitted from objects, or that too much light might not make us blind; and therefore we can adjust the aperture, according as is necessary for distinct vision. The pupil has the resemblance of a truncated conical pipe, whose base is towards the inward part of the eye; for this way it is almost three times larger than on the outward side, that more light might be transmitted through it to the crystalline lens. In the vessels of the iris a liquor is prepared, to be discharged into the anterior chamber of the eye.

§. 955. The *tunica ruyschiana*, drawn over the vitreous humour, is provided with muscular fibrils, which are called *processus ciliares*, of which the fixed beginning is every way in the uvea, and they are arched, because on the fore part the vitreous humour is protuberant. They here shew themselves like rays, passing towards the crystalline. These fibrils are indeed not so numerous as those in the iris, but more gross. The back part of the iris, as also the *processus ciliares*, are besmeared with a very black unctuous matter, that suffocates the light which falls upon the eye too obliquely. When the *processus ciliares* contract themselves, from being bent they become more strait, and squeeze out the vitreous humour, which they drive to the posterior part of the eye, whence because of the resistance it is driven forwards, towards the middle, and moves the crystalline lens forwards.

§. 956. That the ingress of the optick nerve into the eye may be the better understood, conceive the eye to look upon an object, directly opposite to it, and at the same height as itself above the plain of the horizon. Also that a plain parallel

to

to the horizon passes through the middle of the iris, as also a plain perpendicular to the horizon. The optick nerve enters the hinder part of the ball a little below the horizontal plain, and almost in the intermediate place, but very obliquely. Therefore the optical axis, which is a line perpendicular to the cornea, passing through the center of the eye, does not fall upon the optic nerve, but between it and the exterior part of the eye. The optick nerve entering the eye is expanded under the vitreous humour spherically all round about, adhering to the *tunica ruyschiana*, and acquires the form of a very thin villous membrane, extending as far as the separation of the *tunica ruyschiana* from the *uvea*. This expansion of the nerve is called the *retina*, which is very thin and soft, like a very tender mucus. As *Eustachius*^a and *Ruyschius*^b have observed, the optic nerve is perforated in the middle, as *Malpighius* also has taken notice in the fish called Emperor. Where it begins to expand itself, it has greater arteries and lymphatic vessels. The optick nerve is of a white colour, like the brain, from whence it is propagated. But the retina is found not to be so white, because it is immersed in a very black mucus, adhering to the superficies of the *tunica ruyschiana*. Hence this membrane is quite black in infants, not so black at the age of twenty, of a grey colour about the thirtieth year, and in very old age it is almost white.

These are the integuments of the eye; now we must proceed to take a view of the inward parts.

§. 957. Between the cornea and the iris there is a cavity, which is called the *anterior chamber*.

^a Tab. 40. Fig. 1, 2, 3.

^b In Epist. Tab. 16. Fig. 4.

Between the iris and the crystalline lens there is another cavity, called the *posterior chamber*, communicating with the former by means of the pupil. The *anterior* chamber is the greater, and the *posterior* the least. According to Mr. Petit^a the *anterior* is of the dimensions of 11,542 cubical lines, the *posterior* of 7,554. The capacity of both is above 19 cubic lines, which may contain 4,08 grains of aqueous humour. The distance between the inward superficies of the cornea and the crystalline lens is $1\frac{1}{4}$ line. The thickness of the cornea being added, the external superficies is distant from the lens $1\frac{5}{8}$ line. The height of the *anterior chamber*, or the distance of the cornea to the iris, is generally $\frac{2}{3}$ or 1 line. The height of the *posterior chamber* is $\frac{1}{6}$ or $\frac{1}{8}$ line. Both the *chambers* are filled with the same liquor, called *aqueous*, which is thin, very transparent, brackish, and without scent. It is perpetually absorbed and replenishing; it is less thin and pellucid in old men, and refracts light as common water.

§. 958. The *crystalline lens* follows, and is so posited in the middle of the eye, that the axis of the pupil lies in the same right line with it's own. If we consider the length of the eye, it is not in the middle, but nearer the cornea. It is a pretty firm substance, in circuit round, spherically convex on both sides, like the lens of a microscope. The anterior superficies is less convex than the posterior; it is a portion of a sphere which differs in many eyes, the diameter of which is from 6 to 12 lines, but most commonly $7\frac{1}{4}$ or 8. The posterior superficies is a segment of a sphere, whose diameter is 5 lines, seldom $5\frac{1}{2}$.

^a L'Histoire de l'Acad. Royal. An. 1728.

The chord of the lens is generally 4 or $4\frac{1}{2}$ lines, the thickness 2. The lens is composed of several coats, full of vessels, spherical, very closely united. It is very transparent, and to 20 or 30 years of age is without colour, from which time it begins to be slightly tinged with a yellow, and increases in process of time, till about 80 it is as yellow as amber. Also it's hardness changes, for it is softer till 25 years of age, and grows hard till 60. It is softer at the outward surfaces, and harder in the middle. Also by age it's convexity grows less. The lens is included in a membranaceous capsula, which behind grows to the membrane that keeps the vitreous humour. This growing together proceeds as far as the extreme circular limb. This capsula on the fore part is formed by the tunica arachnoidea arising from the uvea. The lens is said to inhere in this capsula loose on every side, into which a viscid liquor is infused, that moistens and nourishes the lens ^a. But perhaps some very minute vessels pass into it out of the capsula, as the artificial injections of *Hovius*, and other anatomists seem to prove. This lens refracts light more than water; for whereas water refracted light in an angle of 60° , $50'$, in the lens of an ox an angle was formed of 24° , $10'$, according to *Hauksbee's* observation. *Robinson* has found, that it's specific gravity is to that of water as 10 to 9.

§. 959. The posterior part of the lens is placed in the vitreous humour, which is a mass denser than the aqueous humour, softer than the crystalline, very transparent, flexible, filling the posterior part of the eye, and exceeding the lens and

^a L'Hist. de l'Acad. Royal. An. 1730.

aqueous humour in quantity. The forefide is contained by the choroides and the ciliar processes. It seems to be a collection of a great number of little vessels inhering in their respective membranes. *Hauksbee* has observed, that it's refracting force is the same as that of water; and *Robinson* takes notice, that it's specifick gravity is nearly the same as that of water^a.

§. 960. The optick nerves arise from the highest part of the medullar substance of the brain, under the *corpora striata*, from whence they tend downwards, and are perfectly united under the *infundibulum*. And then the lamellæ, which arise from the right side of the brain, pass among others, whose origin is from the left side of the brain, and being joined to these form a nerve, which tends to the left eye. And thus also those that arise from the left side of the brain pass to the right nerve, and mingling with it's fibrils tend to the right eye. Then the two nerves separate from each other, enter into the *foramina*, which are at the bottom of the orbit, arrive at the bulb of the eye, in which they are distended and constitute the retina.

C H A P. XXXIII.

Of the passage of light through the humours of the eye, and concerning vision.

§. 961. **T**HE rays of light that are transmitted from any point of a shining or illuminated object, and falling upon the white of the eye, are beat back again, nor do they penetrate into the eye. But they that fall upon the

^a Helsham's Lectures.

cornea proceed in this manner. Let ABC be the object, from the point B let the rays Bd, BF, BD, BE, Ba be transmitted, of which BD falling perpendicularly upon the cornea, which is spherico-convex and transparent, let it pass strait to H through the aqueous humour without refraction; BE falling obliquely on the cornea, is refracted by approaching towards the perpendicular Pp, according to the proportion of the rays that are incident and refracted out of the air into water, §. 878, and passes through the aqueous humour and the pupil, as far as G. In like manner the ray BF passes to I. In this refraction the rays become less diverging, so that many of them may be transmitted through the pupil. Ba and Bd refracted by the cornea fall upon the iris, by which they are reflected, and go out of the eye; by means of such we see an iris and all its colours.

§. 962. Because the pupil is narrow, the rays that are very diverging will not pass through it; which comes to pass, because these, although refracted, did not concur with the others in the point above the retina.

The same things also obtain in the rays emitted from the points of the object C and A, and from all intermediate points.

§. 963. If the object $\Pi\Sigma$ be very near the eye, its rays that are very oblique, as ΠK and Σm , after they have passed through the pupilla, fall upon the very black pigment, between the iris and the vitreous humour at K and m, by which they are suffocated; that they might not disturb the sight if they should pass through the vitreous humour upon the retina, since they could not by any means meet in a point upon the retina.

§. 964.

§. 964. The flatter the cornea is, so much the less will the rays be refracted that fall upon it; therefore they will be the less directed to the pupil, and the fewer will pass. They that do pass will afterwards be less compelled by the other humours of the eye to fall in distinct points upon the retina. In old men their eyes fall away and grow flatter; whence it appears why they do not perceive objects so clearly and distinctly. On the other hand, the more gibbous the cornea is, so much the more rays are refracted by it, are more directed towards the pupil, and will pass in greater quantity. And so generally are the eyes of those which are short-sighted, who therefore see objects more clearly, but only such as are near, whose rays are very diverging, and are to be refracted much, that they may meet upon the retina.

§. 965. The larger the pupil is, so much the more rays, and more diverging, will pass through it, which are emitted from the same point. The narrower it is, so much the fewer rays it will transmit. Now the pupil can be dilated and contracted by means of the muscles of the iris, and this was necessary. Because that we may perceive objects clearly and distinctly, a certain quantity of light was wanting, which may affect the retina neither too little nor too much. So that by contracting or enlarging the pupil, we moderate the quantity of light.

§. 966. Rays that are transmitted through the pupil not very obliquely fall upon the crystalline lens, which is more dense than the aqueous humour. Though the ray *DH* falls directly upon it, and therefore passes without refraction, yet other rays falling obliquely will be refracted, approaching towards the perpendicular, according

to the proportion of rays that pass out of water into glass. By which refraction the rays again will diverge less than before, or will become parallel, or converging, according as EG tends to GL , and FI to IN .

§ 967. The more gibbous is the anterior surface of the lens GHI , and the more solid the lens is, so much the more will the rays be refracted. But the flatter this superficies shall be, or the rarer the lens is, so much the less will be the refraction. Purlblind people seem to have a lens which is very much refracting, and therefore if objects are put near the eye, from whence very diverging rays are emitted, they may be seen by them. On the other hand most old men see only objects that are remote from them, from whence parallel rays are emitted, which can be but little refracted, for which a flatter lens is required. And in old men this is always more solid.

§. 968. Thus the rays are arrived at the vitreous humour, which is something rarer than the crystalline lens; the perpendicular ray HM passes to the point M without any refraction. This being no where refracted in its whole passage through three of the humours of the eye, is used to be called the optical axis. But GL that goes obliquely out of the superficies of the lens, is refracted by receding from the perpendicular LT , and proceeds in the path LO . In like manner M proceeds to NO . And therefore the rays by this refraction are made more converging, and by how much the posterior surface of the lens is more gibbous, so much the rays that are more refracted also converge more. And the flatter that superficies is, so much the less they will converge. By this means the rays of light, which are emitted from any point B of an object, meet again in
a point

a point O upon the retina of the eye. And thus the rays reflected from the points A and C of the object, will meet in the points of the retina X and Y.

§. 969. Wherefore an image of the object ABC will be painted upon the retina in XOY, but in an inverted situation. After the same manner as in a camera obscura, that has but a small aperture, which receives a convex lens, the images of external objects are painted upon a plain.

§. 970. The nervous fibrils of the retina suffer a concussion by the rays, which motion is either continued, or by the animal spirits is propagated to the other extremity of the nerves in the brain, where the common sensorium is. This motion communicated to the mind excites the ideas of external objects; and this is *to see*.

§. 971. The image of external objects is distinctly painted upon a small portion of the retina, about the optical axis, but indistinctly in such places as are remote from this axis. Therefore at one view we can see but a small part of an object, and all the other parts we can see but imperfectly and confusedly.

§. 972. If the object be at such a distance from the eye, that the ray of light emitted from the several points of the object meet again by refraction in as many points upon the retina, the crystalline lens of the eye continues in it's own place. But if the object approaches nearer to the eye, the rays that are emitted from it, being more diverging and as much refracted as before, would not meet upon the retina but behind it. Wherefore the lens, by means of the ciliar processes that contract themselves, is moved farther from the retina, that the rays may unite upon it.

§. 973. If the object is at a great distance from the eye, the rays fall upon it but little diverging, and being refracted as much as before, would meet before they come at the retina. Then the ciliar processes being relaxed, the crystalline lens approaches to the retina, so that the image of the object may be painted upon it.

§. 974. Or when the ciliar processes contract, by which the crystalline lens is brought nearer to the cornea, does it not at the same time become flatter, because of the compression of the bag in which it inheres? Though because of it's hardness it would oppose such a change, yet the mucus that covers it before at H and M will be squeezed towards the ciliar processes, where a cavity is formed in the bag by their contraction; and this would be the same thing as if the lens became flatter on each side. If the lens is mutable, it will become harder and more solid by compression: On the other hand when the ciliar processes are relaxed, the lens will also be relaxed, and will become rarer, but at the same time more gibbous, as well because of it's own figure, as because of the mucus that returns from the processes; which is of some use in vision.

§. 975. Every change that happens to the eye, whether in the widening or straitening the pupil, or in the figure of the lens, or in it's nearer approach to or removal from the retina, is restrained within certain limits, which are more or less extended in different eyes. These limits depend partly on the construction and flexibility of the eye, and partly on years and exercise. And therefore all do not see alike distinctly either near or remote objects. Nay sometimes in the same man the mobility of each eye is confined within different limits.

§. 976.

§. 976. The image of external objects is painted invertedly upon the retina; the upper parts fall upon the lower parts of the retina, the lower upon the upper; those that are at the right side of the eye in respect of the optical axis, fall on the left side of the retina, and those on the left fall on the right side. But why does the mind see objects in their erect situation? Are the nerves which are displayed on the retina inverted in their passage through the brain, so that those which are at the lower part of the eye are terminated upwards in the common sensorium, and so of the rest? Or are the terms *above* and *below* merely relative to our body, which while we say it is placed in an erect posture, all other objects, whose image is alike painted in the eye as that of our body, will be judged to be in an erect situation, in what manner soever they may be painted?

Tab. 15.
Fig. 2.

§. 977. Let the optical axis of the two eyes be ACE and ADG , passing through the centers of the cornea and of the crystalline lens to the retina in E and G . The nervous fibrils are observed to be so disposed, that if the image of the object in each eye L , K , fall upon the points E , G , of the optical axis, the mind sees only one object; as also comes to pass, if the image of the object in the eye L falls within the axis CE and the nose I , and at an equal interval from the optical axis, the image in the other eye K in the same plain may fall between the axis and the part K averse from the nose.

§. 978. This also happens, if the image of the object in the eye L , shall fall between the axis CE and it's part L averse from the nose; and in the other eye K , between the axis DG and the part adjacent to the nose.

§. 979.

§. 979. But if the image of the same object in each eye L and K does not fall at the same time on the parts of the retina aforementioned, Tab. 15.
Fig. 2. the object will appear double. As it happens, if first we look upon the object with both eyes, and then with our finger press either of our eyes upwards or downwards, to the right or left; for then the object will immediately appear double, and in a different place, according to the different pressure of the eye.

980. The same thing also is known, if two objects A and B are placed remote from each other; for as soon as both the eyes attend to the object B, by directing the optical axes to it, the object A appears double, because the two images of this in each eye fall at the external part of the optical axis. But as soon as the optical axes are directed to the object A, the object B appears double, both it's images falling upon the retina between the optical axes and the nose. In a like manner we may explain the following phenomenon. Let there be two candles C, D, which Tab. 15.
Fig. 7. are three feet distant from a perforated paper K. Let the two eyes be in A and B, which together looking upon the candles will see the hole at K to be double. The hole at K being enlarged, both candles will appear as one.

§. 981. Why therefore, since in each eye an image of the same object is painted, does the mind however apprehend but one? Because we have learned by manifold experience, and calling our touch to our assistance, that the object is but single. As by taking a ball between our hands, we have found it to be not two, but one only. The organs of sight and of touch mutually help one another. But when the sense of feeling informs the mind, that an object is simple, of

which a double image is painted in the eyes, when the mind is affected by the eyes after the same manner on other occasions, it judges the object to be simple.

Tab. 15.
Fig. 2.

Others have imagined, that the fibrils of the nerve OQT, PRT meet in one at T, which is extended as far as the sensorium; so that both the nerves being affected in O and P, or only in O, the same perception would arise. But from the observation of Mr. *Du Fay*, this opinion falls to the ground*. For if one eye be shut and the other open, and if we thus enter into a dark room, and then open both eyes, we may perceive the weak light of a diamond with that which was shut, which will not be seen by the other eye.

982. Let a small white circle A be fixed upon a plain black surface, at the same altitude as the right eye. To the right hand from A, and at the distance of two feet, but a little lower, let another white circle be fixed on the same surface. Let a spectator standing near look upon the object A only with his right eye, and he will also see B but obscurely. Then let him withdraw from A in a perpendicular, at a distance from it of 6, 7, or 8 feet, or more, and the object B will no longer appear. For then the image of the object B falls upon the optical nerve, where it enters the eye. Wherefore then is the object not seen, if this nerve be the instrument of sight? Is it not because then the image falls upon the middle of the nerve, where there is a cavity, and where the extremities of the fibrils cannot be affected?

Or secondly, since the blood-vessels that run through the middle of the nerve here enter the bulb, can the image of the object B falling upon

* L'Hist. de l'Acad. Roy. An. 1735.

such a blood-veffel be perceived by the mind, since not an artery but a nerve is the instrument, which propagates motion to the common sensorium? *Mariot*, *Perrault*, *Pecquet*, have disputed at large about these appearances, to which *Bernoulli* has added reflections that are still more subtle ^a.

§. 983. From what we have hitherto explained it manifestly follows, that rays of light have not their emanation from the eyes themselves upon the objects, from whence they are reflected back again to the eyes, as the Stoicks have taught. For in a place that is quite dark we can see nothing, in which however we ought to see objects in the same manner, if light proceeded out of the eyes. *Pliny* ^b indeed mentions something like this of *Tiberius*, *Plutarch* of *Marius*, and *Briggs* ^c of an ingenious *Britain*, and *Willis* after drinking of a generous wine. *Schenckius* ^d takes notice of a certain Countess in the same circumstances: and it is also affirmed of *Sabellicus* the historiographer. But we doubt much whether the observations were rightly taken; besides that they are said to be cases very rare, and not at all natural, from whence nothing can be concluded. It is most likely, that the very tender retina of these people could be moved by a very little light, and that so they might see objects in darkish places.

§. 984. Nor according to the *Pythagoreans* and *Epicureans* ^e, are visible species emitted from objects, which at their first emission are very great,

^a Comment. Acad. Petro. V. I. p. 314.

^b Hist. Nat. l. 11. c. 37.

^c Ophthalmograph. c. 5. §. 12.

^d Lib. 1. Obit. de Morb. Oculor.

^e Lucret. l. 4. v. 46.

and decrease continually the further they go, till they arrive at such a smallness as will permit them to enter the eye, that the mind may perceive them. If this hypothesis were true, we should see objects in the dark as well as in open light. Which difficulty also attends the opinion of the *Platonicks*, who imagined, that both the objects and the eye emitted their several effluvia, which met with one another in the midway, embraced one another, then returned and made their reports to the eye, and so to the mind.

§. 985. The clearness with which objects are perceived is greater or less, depending on many causes, which are either solitary, or several concur together. Greater clearness depends, first on the greater quantity of light reflected by the object, and is in the first place, if the object be near, nor the light intercepted by the air: for *in vacuo* near and remote objects would be seen with equal clearness. Secondly, if the object be white, or painted with a lively colour. Or thirdly, if the figure of the object be such, that it can reflect many rays to the eye.

Secondly, the clearness depends on the amplitude of the pupil, and the mobility of the iris; for the wider the pupil is the more rays it can transmit.

Thirdly, it depends on the transparency of the three humours of the eye, which enables them to transmit almost all the light that falls upon the cornea.

Fourthly, to this also concurs the tender and sound condition of the retina, and of the whole optick nerve from one end to the other.

§. 986. Hence it appears why short-sighted men see objects more clearly than old eyes, because they require them to be nearer. By looking

on an object for a good while, do we not see it more clearly than at first, because we gradually dilate the pupil more and more?

§. 987. If the four conditions mentioned §. 985 should concur together, objects would be seen very distinctly. If one or more of these four causes be less perfect, objects will not appear so clearly: and the more these four causes shall want of their due perfection, so much the more obscure the objects will be.

§. 988. Objects are distinctly seen, first when the rays emitted from them, after they have passed through the three humours of the eye, and have been reflected from the same point of the object, meet in a point upon the retina.

Secondly, vision is chiefly distinct, when the image painted upon the retina is large in respect of the object, so that almost all the rays form so many different points of the image upon the retina, as are the points of the object from whence they are emitted: and therefore near-sighted people see more distinctly than such as are long-sighted; as likewise we always see near objects more distinctly than those that are remote.

Thirdly, when objects are neither too much nor too little illuminated.

Fourthly, when we behold the same object a long time and with attention, by viewing it in every part with our sharpest sight, and at the same time by accommodating both the amplitude of the pupil and the humours of the eye to the rays of light, that they may be accurately refracted to form a distinct image.

§. 989. The rays of light CA and BA that Tab. 15. come to the eye A from the extreme points of Fig. 3. the object, form an angle BAC, which is called the *optical* or *visual angle*.

§. 990. By this angle we measure the apparent magnitude of objects ; therefore those things which are seen under equal optical angles, appear to be equal, and paint equal images upon the retina : those which are seen under a lesser angle, appear lesser, and paint lesser images ; and again, those which appear under a greater angle, paint greater images upon the retina, and appear greater.

Tab. 15.
Fig. 4.

§. 991. Whatever things are seen at one view, are commonly contained within an optical right angle. For let the rays XB , ZB , form a right angle ; these being produced cannot pass through the pupil DE , though by refraction they may diverge less in the aqueous humour, but they fall upon the iris : therefore the rays that will pass through the pupil must comprehend an optical angle which is less than a right angle.

§. 992. Therefore the wider the pupil is, so much greater the optical angle may be, and on the contrary : hence it is understood, why a large and near object cannot be seen at one view ; and why the whole of it may be seen, when viewed at a distance.

Tab. 15.
Fig. 5.

§. 993. If the same object BC be placed at various distances from the eye O , it will always appear to be so much the less as it is more remote from the eye : for the optical angle BOC is less than the angle boc .

§. 994. The apparent magnitude of objects is in a reciprocal ratio of the distance from the eye : for the apparent magnitude depends on the optical angle, which decreases when the distance increases. The object BAC is seen under the angle BOC , which if it be little, the right line CAB will not sensibly differ from the arch CAB . This being divided into two equal parts
at

at A, makes the angle AOC to be half BOC. Now let the object AC be placed in c, at half the distance OC, and Ec will appear under the angle EOc, which is equal to BOC, or as big again as in AC.

§. 995. Let OKF be an eye, upon whose retina the image KF of the object BC is painted; therefore the magnitude of the object BC will be to the magnitude of the image FK upon the retina, as CO to OF. Therefore if BC be a tower 4000 inches high, which is seen at the distance of a mile, or of 120000 inches, the image KF will be less than $\frac{1}{30}$ part of an inch.

§. 996. Since the image of a great object is very small upon the retina, many points of the object emit rays, which fall upon the same nervous fibril of the retina, which therefore is agitated by different concussions at one and the same time, and can represent nothing distinctly to the mind; wherefore the parts of a very remote object can never be distinctly seen. He that has the sharpest sight can never distinguish stars in the heavens that subtend an angle less than 30 seconds. The greatest part of mankind can hardly distinguish objects that subtend an angle of a minute. If a white circle be fixed upon a black wall, and is illuminated with day-light, it can hardly be seen by the most acute eye when it subtends an angle only of forty seconds, or when the distance from the eye exceeds the diameter of the circle 5156 times; for then the image of the circle in the eye is only $\frac{1}{8000}$ part of an inch.

§. 997. Also the mind judges of the distances of objects by the assistance of sight, which is performed after various manners.

First from the angle which is formed by both the optical axes CA and DA meeting in A. But Tab. 15.
1 4
this Fig. 2.

this concurrence is made by the motion of the eye, which is sensible to us in small distances; so that by the magnitude of the angle CAD we accustom ourselves to judge of the distances of near objects.

Hence if we are used to judge of distances by the help of both eyes, we cannot distinguish them by one eye alone; for then the angle CAD is not formed; as appears from hence. If we tie a little bit of a stick cross the other, and a little ring be hung up at the same height as the eye, at the distance of two or three feet from it; when either of the eyes are shut, we shall not be able to make the stick pass over the ring, no not at six hundred trials, which when both eyes are open we shall do without any difficulty: yet one-eyed people learn to know distances by long use. Now because in greater distances there is hardly any difference in the angles CAD , such at least as is discoverable by the eye, we cannot by any means form a sure judgment about great distances.

Secondly, we judge of distances from the apparent magnitude of known things, compared with their real magnitude.

Thirdly, also from the apparent image being either distinct or confused; for the more distinct the image is, so much the nearer the object has been used to be.

Lastly, from the strength and vivacity of the light reflected from objects, which is less from the more remote, and contrarywise. And though we may call to our assistance all these four manners together, yet by sight alone we shall never distinguish the true distance of objects: yet constant and daily exercise enables us to judge tolerably well of smaller distances.

§. 998. But there are innumerable other circumstances about vision, which we must not undertake

undertake to discuss in these elements. I shall only propose some of the more entertaining of them, under the form of problems.

First, when we have been for some time in a place much illuminated, and then go into another much less bright, why do the objects at first seem obscure? Nay, why are we blind as it were for some time? because in an illuminated place the pupil is contracted, that the retina may receive no injury from the multitude of rays, though it will be very much affected. And secondly, when the mind has been accustomed to attend to these greater motions, it does not perceive these lesser influences. When in this condition any one shall enter a darkish place, as now a very little light passes through the pupil, and the retina will be but little affected by it, the mind having been accustomed to stronger impressions hardly perceives any thing. Hence follows some kind of blindness, and all things continue obscure, till the pupil by degrees is a little enlarged, and more light passes through it, and the mind can accommodate itself to milder impressions.

Secondly, cannot a man that is in darkness easily see those that are in open day-light, but on the contrary cannot be seen by them? Because he receives a great plenty of light which is reflected by them, but the very little light which is reflected from him to them will much less affect their retina, than the other luminous objects in open day; therefore the mind does not attend to those lesser concussions.

Thirdly, whence are those lateral rays, which seem to adhere to the extremities of the flame of a candle, to an eye either winking or full of tears? Mr. *de la Hire*^a has explained these very

^a Memoir. Mathem. p. 277.

well,

Tab. 16.
Fig. 1.

well, and at the same time has shewn Mr. *Robault's* mistake. Let B be a candle, H and I the eye-lids, which in winking wipe away the moisture of the eye. This being gathered together, and adhering to the eye and eye-lid, forms a kind of triangle. As the light of the candle falls upon this, and indeed upon the top of it, it is refracted, and is spread upon the retina between D and L as the rays refracted by a prism form an oblong image: so that a streak DL will adhere to the image of a candle upon the retina, which will be judged to proceed from the lower part of the candle, and more particularly from BM. Thus also from the humour at I rays will be displayed between X and K, which will seem to be derived from BN: therefore if an obstacle be interposed at P, that intercepts the upper rays of the candle, the streak DL vanishes, or the rays BM will be lost. But this moisture at the eye-lids H and I will be more copious in an eye full of tears, and then the phenomenon will become more sensible.

Fourthly, if a man rubs or squeezes his eye in the dark, why do sparkles of fire seem to arise? Is it not because when we see, the light is used to shake or squeeze the nervous fibres of the retina, and when the nerves are pressed in a like manner by the vitreous humour, though by another cause, the mind will form the same judgment? Therefore if now the fibrils are pressed, as before by some of the coloured rays, the mind will perceive the same colours. This happens when in the dark we press the corner of our eye, that it may withdraw farther from our finger; for then we see a circle painted with such colours as are in a peacock's tail. Then our finger and eye being at rest, in a second of time the colours vanish, which again return on squeezing the eye.

Fifthly,

Fifthly, why is a fiery circle to be seen, if we light up a match, and then whirl it swiftly about? Because the extremities of the nerves stand out like a shag, which when shaken tremble for some little time with an oscillating motion, and while this continues the mind perceives the object. It is probable that they continue for the space of a second, as we may collect from the observation about colours, that arise from the pressure of the eye with our finger in the dark. If therefore the string be whirled about with such rapidity, as that it finishes its rotation within a second, the light emitted from it in a certain point of the circle, and exciting a tremulation of the nerve in the eye, proceeds again from the same point of the circle, and again affects the same nerve, before the former tremulation has quite ceased. Therefore the nerve will continue to tremble in the same manner, as if the lucid body had always continued in the same point. And since the same things happen in every point of the orbit described by the match, it will all seem to be a fiery circle. For the same reason a string stretched and vibrated very swiftly will not only seem to be two, but appears of that thickness and figure which the path is, which it describes by moving to and fro.

Sixthly, why is the aqueous humour wanting in the eyes of fishes, and why is the crystalline lens of a globular figure? Because to animals that swim in water the aqueous humour would be useless; for the rays coming out of water into an aqueous humour would not be refracted. As therefore vision, which in us is performed by a threefold refraction, is performed by two only in fishes, a lens much more refracting was required than that in human eyes, and therefore it is globular, by which also they can see more objects.

Hence

Hence divers see objects confusedly under water, unless they use magnifying glasses.

Tab. 16.
Fig. 2.

Seventhly, when we behold the same object C with our right eye B, do we not refer it to the place D; and viewing it with the left eye A, do we not refer it to the place E, and seeing it with both our eyes together, do we not refer it to a place which is intermediate between D and E, because we judge objects to be placed in that right line, in which the rays emitted from them approach to the eyes? And the mind tacitly corrects the places of the object seen at D and E, by taking an intermediate point F?

Eighthly, why do infants that are new born for the first four or five weeks distinguish no objects, nor exercise the faculty of sight? which also happens in many other animals. Because in infants the cornea is much grosser than in adult persons. Besides it is flatter, something wrinkled, and less transparent. But chiefly because their eyes have no aqueous humour, or in too little quantity, so that the refraction of light, necessary for distinct seeing, cannot be performed in their eyes. Therefore there must be time allowed till the aqueous humour has filled both the chambers, till the cornea is propelled outwards, till it is condensed, and the wrinkles are smoothed.

C H A P. XXXIV.

D I O P T R I C K S.

§. 999. **F**ROM whatever point of the object rays are emitted, which diverge from one another, when they arrive at the eye the mind judges that they came in the same right line, in which they fall upon the eye. Therefore it sees every point of the object in that place, in which these rays meet, when continued back from the eye to the object.

§. 1000. If therefore the rays are refracted by the medium, through which they pass, and thus come to the eye, the mind will judge them to have come from that point of the object, when put in that place, in which the rays meet when produced back from the eye.

§. 1001. If the vessel *C B C B* be filled with water, to a spectator *MR* that views the vessel downwards, it's bottom will seem to be raised. For let a point *A* be conceived at the bottom, (and the same will obtain of the whole bottom) and let it be illuminated by the light *b c A*; from it the rays *A g*, *A z*, proceed diverging, which coming out of the water into the air, and being refracted by receding from the perpendicular *ff*, will be carried to *g M*, *z R*. Now the eye at *MR* receives them, as if they had come from a nearer point *a*, so that the point *A* will be seen at *a*, or the bottom will seem to be raised. The true place of the point *a* will be known, if *A a S* is drawn perpendicular to the superficies of the water *CC*, and if *A S* be taken in proportion to *a S*, as 4 to 3. Tab. 16.
Fig. 3.

The

The same thing will happen, if a piece of money be put at the bottom P of an empty vessel, and a spectator S retires so far, as that he can no longer see the money, because the side of the vessel CB is interposed; then if water be poured into the vessel, the spectator S will see the money as if raised to f , by means of the refracted ray PCS .

Tab. 16. §. 1002. Hence also may be understood, by
Fig. 4. what means an entire oar CDO , seen obliquely in clear water AB , exhibits the appearance of one that is broke CDN . For let us conceive E to be a point of it under the water, from whence rays EG , EK , are emitted, which being refracted become GH , KP . Therefore the eye placed in HP sees these, as if they had come from the point F ; so that part of the oar DO will appear in the right line DN .

Tab. 16. §. 1003. If a glass be placed between the eye
Fig. 5. Z and a point of an object A , the two surfaces of which BB , CC , are parallel to one another, and the axis of the eye is perpendicular to these surfaces; the object A will appear to be nearer the glass in a .

For the rays Ag , Ae , at their entrance into the glass, are refracted towards the perpendicular, and brought into the path eb , gk ; and at their going out into air, they recede from the perpendicular into bp , kn , which being produced backwards meet at a , and are parallel to Ag , Ae .

Tab. 16. §. 1004. The object AE seen through a plain
Fig. 6. glass $BBCC$, seems to be enlarged.

The angle under which it would be seen, if the glass were taken away, is AQE . But the ray Ag is refracted by the glass to gL , and the other ray Eg to KL , both which at going out of the glass into air, are refracted in LQ to Q .
Wherefore

Wherefore the eye receives these under the angle aQe , and therefore the object AE will appear of the magnitude ae , if it be seen in that place. But since it appears nearer, by §. 1003, it will scarcely be enlarged.

§. 1005. If a glass of many sides $ABCD$ be Tab. 16.
interposed between the object F and the eye O , Fig. 7.
the object F will appear to be multiplied.

By means of the rays that pass through BC , AD , the object will be seen by the eye O to be in the right line OF . And by means of the rays FX falling upon the superficies CD , and refracted at X and H , and thence passing to O , it will be seen in L . And by means of the rays FZ , incident at BA and refracted at K , and thence to O , it will be seen in M .

§. 1006. Images formed by the refractions of Tab. 13.
plain superficies are like their objects, always Fig. 7.
erect, alike posited as the objects, and lye on the same side.

Let PQR be an object radiating upon the plain refracting superficies ACB , to which let the perpendicular PA , QC , RB be drawn, in which let there be taken the parts Ap to AP ; Cq to CQ , and Br to BR , in the ratio of the sine of incidence to the sine of refraction. Then the foci p , q , r , will constitute a like image, and having a like situation with the object, since the parts pq , qr , are in the same ratio as PQ , QR . This is evident of itself, since the object is parallel to the refracting superficies. But if it be inclined to it, let it be produced till it cuts it in D , also the image being produced will cut this in D . For let the perpendicular BrR approach to D , and since the lines Br and BR are to one another in a given ratio, they will vanish together. And because the triangle pDP is cut by
the

the parallel lines qQ and rR , it will be as pq to PQ , so is qD to QD , and so is qr to QR . And therefore $pq \cdot qr :: PQ \cdot QR$. In like manner, if the rays coming to the foci p, q, r , are refracted by another plain superficies, whether parallel or inclined, their second foci will form another image like to the former, and like the object.

Tab. 16.
Fig. 8.

§. 1007. If between a point of the object A and the eye O be placed a lens of glass that is convex on both sides, the point A will appear in a , which is more remote from the lens than the object itself. The rays Ab, Ab , emitted from A , and falling upon bb , are refracted towards the perpendiculars pp , and so become less diverging. At their going out of the superficies cc they are refracted from the perpendicular cq , by which they are made still less diverging, in cd, cd . These protracted backwards meet at a , and therefore enter the eye O as if they had proceeded from the point a .

Tab. 16.
Fig. 9.

§. 1008. An object AE , viewed through a lens by an eye O near the lens, also appears enlarged. For the rays Ab, Eb , transmitted from the extremities of the object A, E , and falling upon the lens LK are refracted, that going out again they may converge the more to O , and form the angle cOd greater than AOE , under which the object would be seen without the lens; by which the object will appear enlarged. But whereas it is seen also in a more remote place a e by §. 1007, it will appear much more enlarged.

§. 1009. If the lens be spherical and concave, the object seen through it will appear as posited between the object and the eye, nearer the lens, less in magnitude, and upright.

Let

Let A be a point of the object, emitting divergent rays Ab , Ab ; these refracted in the lens will be more divergent to ee , and at going out will farther diverge in ed , ed . Therefore the eye placed in dd receives the rays as if they had come from a nearer point a . This point a is the *imaginary Focus*. Tab. 16.
Fig. 10.

Now let there be an object AE , which by an eye at O is seen under the angle AOE . Let a concave lens SS be placed in the middle, then the rays emitted from the extremities A and E , which can arrive at the eye O , are Ab , Eb , which refracted are bc , bc ; and then they go on in the paths co , co ; now since the angle co is less than AOE , the object will appear less in ae , and erect. Tab. 16.
Fig. 11.

§. 1010. If an arch of a circle PQR be described from the centre of the lens E , and this be considered as the object, it's image pqr will be a like concentric arch. It's length will be to the length of the object in the same ratio as their distances from the common centre E , and the image will be erect or inverted in respect of the object, according as it lies on the same or the contrary side. Tab. 13.
Fig. 8, 9,
10, 11.

The proposition will be evident in all concentric superficies, from the bare inspection of fig. 8. because the parts of these superficies are alike opposite to the parts of the concentric object. But in the lens the foci of the parallel rays lye in the concentric arch GFH , since Pp and Qq are third proportionals to the distances PG and PE , as also to QF and QE ; and therefore the image pqr is a concentric arch. Because the axes of the rays are considered as right lines passing through E , the angles pEr and PER will be equal; therefore the ratio of the magnitude

of the image to the object will be as the ratio of their distances from the point E. As therefore the extremities P and p lye on the same or opposite side from E, so also Q and q will lye, and likewise R and r.

1011. The less the circular Object PQR is in respect of the distance from the point E, so much the more it approaches to a right line, which also obtains in the image; therefore a plain object at any notable distance from the lens, will have nearly a plain image.

§. 1012. If the eye be that of a man in years, which, because of the cornea or the crystalline lens being too flat, cannot sufficiently refract the diverging rays of near objects, so as to make them meet upon the retina; by means of a convex lens put before it, the rays transmitted from objects may be made less diverging, so as they may be more easily refracted by the eye, and made to meet upon the retina; wherefore old men, by means of a perspective-glass, may again clearly and distinctly perceive near objects.

§. 1013. The use of perspective-glasses is not very ancient, although it has been long known, that many things may be set on fire by the rays of the sun passing through spheres of glass. The invention of lens's for the use of old men seems to have been between the years 1280 and 1311, *Roger Bacon*^a, *Alexander de Spina*^b and *Salvinus Armatus*^c, also were acquainted with their usefulness.

§. 1014. Because short-sighted men refract the rays of objects too much by their eyes, and therefore see only objects that are near them distinctly,

^a Perspect. p. 3. d. 2. cap. 3.

^b Redi Epist. ad Falcon.

^c Act. Lips. An. 1740.

the rays of which have a great divergency, but refract too much the rays of remote objects; these may also see objects distinctly by means of a concave lens, which will disperse the rays more from one another.

§. 1015. If a convex lens is a portion of a lesser sphere, or if it be a whole small sphere, it will very much enlarge objects, so that all their parts may appear distinct; and then it is called a *Microscope*. The whole Microcosm has been discovered in this last age by the help of such lens's. The chief observers seem to have been *F. Stelluti*, and he indeed was the first, having described the most minute parts of bees in the year 1625. Then afterwards were *P. Borellus*, *Power*, *Hooke*, *Grew*, *Malpighi*, *Leeuwenhoek*, *Bonannus*, *Griendelius*, *Joblot*, *Reaumur*, who have given us microscopical observations, to the great improvement of science.

§. 1016. That it may be understood of what magnitude an object appears to be, both when seen with the naked eye, and also with the Microscope, let PQ be supposed to be the object, which is in the focus of the lens AE , near to which the eye being placed, it will perceive the object distinctly under the angle PEQ . But let the natural eye be removed to the distance LQ , in order to see the object distinctly; the angle PLQ will be that, under which the object will be seen. But the angle PEQ is to the angle PLQ as LQ to QE . And the apparent magnitude of an object is as the optical angle; so that the magnitude of an object seen through a Microscope, will be to that seen by the bare eye, as LQ to QE .

§. 1017. But if a single lens does not sufficiently enlarge the object, another lens, and even a third may be added; which invention is owing

to *Drebbelius*, a *Hollander*, who in the year 1621 exhibited such a compound Microscope, as *Huygens* testifies^a. This was afterwards improved and corrected by various artifices; as also how the objects might be illuminated by plenty of light, much enlarged and made distinct, and that great portions of them might be examined at one view. In these compound Microscopes the least lens is placed near the object, and therefore is called the object-lens; and that which is near the eye is the *ocular* lens. But how the rays are to pass through these lens's, may be sufficiently understood by an inspection of the figure; as also how the object *AB* may be illuminated by a speculum *SS*.

Tab. 17.
Fig. 1, 6.

§. 1018. Of a convex and a concave lens, placed in a tube at a certain distance from one another, a machine is composed, which is called a *Telescope*; by the help of which objects that are remote may be seen distinctly, enlarged, and erect. The rays emitted from objects, or reflected by them, arrive at the eye in the following manner, as *Molyneux* has very well explained. Let the object be *ABC*, from whose highest point *A* proceed three rays, *a, a, a*, from the middle point *B* the three rays *b, b, b*, and from the lowest point *C* the three rays *c, c, c*. These cross one another before they enter the tube, and having entered the tube they fall upon the convex lens *ZYX*, which is called the object-lens; by which they are refracted that they may meet at *f, e, d*, and there paint an image of the object. A concave lens *GL* is put between the concurrence of the rays and the object-glass, at such a distance from this concurrence, as is equal to

Tab. 17.
Fig. 3.

^a Dioptrica, p. 221.

that

that of the imaginary focus of the concave lens. This lens, which is called the eye-glass, by it's refraction makes those rays parallel, which proceed from one and the same point of the object, and causes them to diverge to T and R. The eye receiving these parallel rays, as if sent from a very remote object, refracts them that they may meet upon the retina, and paint the image of the object in T E R ; which since it lies in the same situation as if the object had been viewed by the naked eye, it will appear in an erect posture and distinct. And whereas in Fig. 3. it appears under the angle T P e, to which f h e is equal, and which is much greater than the angle f y e, under which it would be seen by the naked eye ; the object will appear enlarged in the ratio of e y to e h. The visible aperture depends, partly on the magnitude of the object-glass, partly on the aperture of the pupil ; which being subject but to small mutations, this Telescope, to which the eye is to be put very close, requires only a small concave lens. And hence it can only be short, hardly above a foot long, so that it is of but little use in viewing very distant objects.

Tab. 17.
Fig. 4.

§. 1019. This tube is called *Batavian*, because it was found out in the *Low Countries*, at *Middleburg* in *Zealand*, and was there constructed by *Zachary Johannides* and *John Lipperhey*, about the year 1590^a. Though the invention is by some ascribed to *Metius*, by others to *Porta*^b, by others to *Galileo*, but not with so much reason. It is not probable it was known to the ancient *Egyptians*^c, or that by it's assistance ships could be discovered at the distance of 600 miles, from the

^a P. Borellus de Telescop. Invent.

^b Kepler in Nunc. Syder. p. 16.

^c L'Hist. de l'Acad. de Belles Lettres, Tom. I. p. 136.

watch-tower that was erected in *Pharos* of *Alexandria*. For this could not be done by reason of the curvature of the earth's surface.

Tab. 17.
Fig. 5. §. 1020. *Kepler* was the first that supplied the defects of the *Batavian* tube, describing his emendations of it in his opticks published 1611. *Fontana* assumed the invention to himself, An. 1608, which others ascribe to *Rbeita*, who published his work in the year 1645^a. And thus arose the *Astronomical Telescope*, consisting of two lenses, which were convex on both sides. Let there be a very remote object *ABC*, from whose highest point *A* rays are emitted, denoted by the little lines *a, a, a*, and from *B* the rays *b, b, b*, and from *C* the rays *c, c, c*, as denoted by points. Before these rays enter the tube they somewhere intersect one another, and falling upon the object-glass *XYZ*, they are refracted by it, that they may meet in their foci *f, e, d*, and there paint the image of the object. Let the eye-glass be *ghl*, as far removed from the foci *f, e, d*, as is the distance of that focus, the rays being supposed parallel. Likewise let *eh* be the distance of the focus from the eye-glass *ghl*. The distance *Yh* will be equal to the sum of the distances of both foci. Let the eye *O* be something more distant from the lens than is it's focus; the object will appear distinct to it, enlarged, but inverted. And it's amplitude depends on the magnitude of the eye-glass. To the naked eye the object would have appeared under the angle *aYc*, to which *lYg* is equal. But through the Telescope the object is seen under the angle *lOg*, which angles are in the ratio of *hO* to *Yy*, or of *he* to *eY*; that is, as the distance of the eye-glass to that of the object-glass.

^a Hist. Acad. Reg. 1. 5. S. 1. c. 7.

§. 1021. Because terrestrial objects appear inverted through this tube, and therefore are not very easily known, two other eye-glasses have been added to this telescope, so that it is composed of four lens's, of which the three eye-glasses are set at an equal distance from one another. The rays pass through these, as is exhibited in the scheme, and thus the object will appear erect, nearer to the eye, and magnified, as in §. 1020. Tab. 18.
Fig. 1.

1022. Telescopes of this kind of 20 feet long, and scarce longer, may serve for viewing terrestrial objects; and that because of the continual motion of the aerial particles, which becomes visible, and is the reason that objects seem to be affected with a tremulous motion.

§. 1023. These dioptrical Telescopes are subject to some defects, because of the different refrangibility of the rays. For let there be a glass AB, and parallel rays EA, CI, FB; let the least refrangible rays meet one another in G, the greatest in H; there it will be GI to IH, as 28 to 72, and GH will be $\frac{1}{28}$ of GI. Through G let KL be drawn, and MN through H, perpendicular to the axis CIG. Then MN will be $\frac{1}{28}$ part of the breadth of the glass AB, and KL will be $\frac{1}{27}$; therefore OP, which is the least space in which the rays are collected, will be nearly half MN, and therefore $\frac{1}{53}$ of AB. Therefore the rays proceeding from one point of the object will not meet in a point behind the glass, and consequently every point of the object will be seen but indistinctly. This error is increased in the passage of the rays through the eye-glasses; and thus through telescopes objects appear as tinged with colours. When the great *Newton* perceived these defects, and many others, he corrected

rected these telescopes, and substituted reflecting one in their stead; of which we shall treat in the next chapter.

CHAP. XXXV.

CATOPTRICKS.

§. 1024. **L**IGHT emitted from a luminous body, and impinging upon objects, is reflected all round about, if the surfaces of those objects are rough and unequal; but if the surfaces are smooth and polished, the light will be reflected according to some particular direction.

§. 1025. The reflexion of light is performed, either by the anterior surface of a body, if it be opaque; or by the posterior surface if the body be pellucid; or by both in transparent bodies.

§. 1026. Sir *Isaac Newton* has discovered, and demonstrated at large^a, that the reflexion of light by the anterior superficies is not to be imputed to it's striking against the solid parts of bodies, but to certain repelling forces proceeding from the bodies, and acting beyond the surfaces. For when a small beam of the sun falls upon a hair, thread, needle, straw, and such like bodies, a much greater shadow is projected by them, than can proceed from tangent rays. And the same thing happens if they are surrounded by water. And therefore the light is diverted from it's strait way by a force that repels it, and issues from the bodies.

First, let the superficies of metal or glass be rough; and light will be dispersed every way by

^a Optic. l. 2. p. 3. §. 8. l. 3.

it. Let the superficies be polished, which is performed by rough powders. The greatest part of the roughness will be taken away from the superficies, yet it will still continue very uneven, because of the scratches which are made by the powders, as also by reason of the pores of the body. Notwithstanding which, no sooner is the polishing in some measure performed, but the superficies of the body begins to shine, and to reflect light regularly, as if it had been completely polished. Now this could not obtain, unless there were some force extending beyond the superficies of the body, which reflected the incident rays before they could arrive at the solid parts of the body.

Secondly, this force therefore forms a kind of virtual superficies, which reflects light. Unless it were so it can hardly be conceived how it comes to pass, that in glass specula we observe only two images of objects, and not innumerable images. For this would be the case if it were the solid particles that reflected light. For in the glass there are many strata of solid parts, each of which, by reflecting the light, would produce a variety of images.

Thirdly, nor is it the posterior superficies of bodies that reflects light, but the attracting force, which proceeding out of that superficies draws back the rays that were going out of the body, and so repels them, as we have exhibited in Tab. 11. Fig. 7. For this posterior reflexion or rather inflexion of light, and it's return, is brought about as soon as it falls more obliquely than under an angle of 40 or 41 degrees, at it's going out of glass into air or vacuum. Therefore it cannot be conceived how air, which is a very rare fluid, should stop up the pores of the glass, whereas at a less obliquity it suffers the approaching light to pass.
But

But the air has no share in this, because in vacuo the light returns more strongly, and less of it seems to go out of the glass. For here is nothing that can shut up the pores of the glass. Now reflexion is not performed by the solid parts of the glass that constitute the superficies. For when water, oil, or another glass is added to the superficies, there is no reflexion of the light, but it passes through. But then the solid parts of the superficies are not changed. What is changed then? Why, the action of the attracting virtue, because of the attracting power of the water, oil, or the other glass that was added.

Tab. 17.
Fig. 2.

§. 1027. Therefore there is a two-fold return of light from glass and other pellucid bodies. That which is made by the anterior surface arises from a repelling force; that which is made by the posterior surface arises from an attracting force. Let there be a body *ABCD*, out of whose upper surface *AB* there proceeds a repelling force as far as *IH*, and an attracting force as far as *KL*. The ray *OP* falling very obliquely upon the repelling force *IH*, is much retarded, is inflected at *Q*, repelled into the path *QR*, and reflected to *RS*. But if a ray *op* had fallen upon *IH* less obliquely, it will go strait forwards with a greater force, though a little drawn out of it's way; so that it will describe a small curve *pq*, arriving afterwards at the attractive force *KL*, where it is accelerated, and describes the curve *qr* in another situation. The return of light from the posterior superficies is described in §. 1026. All transparent bodies seem to be surrounded by two such different forces.

§. 1028. Hence we may understand what bodies are opaque. First, atoms that are without pores. Secondly, particles whose pores are too narrow to transmit

transmit light. Thirdly, the greater bodies from whose superficies there proceeds a strong repelling force. Fourthly, large bodies whose parts leave ample pores between, and which are at a great distance from one another, so that they can exert their whole force of attraction upon light; by which it comes to pass, that light is transmitted in continued curve-lines to the several particles, is unequally reflected by them, and so being as it were intercepted is hindered from passing, or after it has passed it goes out with an irregular motion, and cannot any more be seen. Therefore as soon as the pores of these bodies are filled with any medium that attracts light, the light can no longer be impelled by so irregular a motion, or move in the same curves by the attracting force of the parts; but the attracting forces conspiring with those of the medium, and also of the parts, the light will move in right lines, and therefore will pass through the body, as may be gathered from an inspection of the same scheme. Tab. 15.
Fig. 6.

§. 1029. Therefore by filling the pores of the body, of opaque it becomes transparent. The more that medium which fills the pores shall attract light, so that it may act upon it with the same force as the parts of the body, the more transparent the body will become. All this is confirmed by experience. Clean white paper is generally opaque; but fill it's pores with water, or moisten the paper, and it will be transparent. But if you fill the pores with oil, this attracts light more forcibly than water, and the paper will become much more transparent. But all kinds of oil do not equally attract light. The great *Newton* has observed, that oil of turpentine has a refracting force, which is to that of oil of olives as 13222 to 12607. Therefore dip your paper
in

in oil of turpentine, and it will then be almost as transparent as glass, and much more so than if dipped in oil of olives.

If the clearest glass be beaten to powder, it will be very white, but altogether opaque, as will appear when laid upon a glass plain. Fill the pores of the powder with water, and it will begin to be something transparent. Fill the pores with oil of turpentine, and it will then be transparent. Make the parts again to approach nearer by melting the powder, and it's former transparency will return.

Shake the transparent white of an egg into a froth, and the froth will be very white, but opaque. When it ceases to froth the former transparency will return.

Shake vinegar and oil of olives together, and though each is transparent by itself, yet when conjoined the fluid is very opaque.

Water is very transparent; let it be reduced to vapour by means of fire, and it is much less transparent. Hence in the laboratories of dyers and brewers there is so great a darkness, arising from the vapours. And hence these rising vapours, as also the smoke of chimnies, form dark clouds floating in the atmosphere. The stone called *oculus mundi* is opaque, but it becomes transparent when it's pores are filled with water. The great *Huygens*^a has observed something like this in gypse. For when he had put some gypse about Mr. *Boyle's* receiver, which had been steeped in water like lime, the matter was yet opaque; but after he had put turpentine and oil to it, this penetrating into the pores of the gypse made it transparent. From hence also it may be easily under-

^a Philof. Transf. No. 122.

stood, why ice is transparent when it is first generated, and why afterwards it becomes opaque, as soon as bubbles are produced in it, either from the intercepted air, or from any other cause. But there are many other like phænomena, the reason of which will be obvious. Pure metals, because very homogeneous, are not of much use for forming specula; but if several are mixed together, though then the parts of the mixture will not be very congruous, and but little cohere, intercepting irregular pores, yet thence a certain metal arises, which reflects light very strongly, and is very fit for making specula^a.

§. 1030. Yet it is not to be thought, that light is therefore a body different from all other bodies, because it does not pass through the open pores of bodies; for we have many examples of this kind. Water does not pass through the wide pores of a hair-cloth of camels hair; no nor water, wine, beer, or spirit of wine through the pores of wooden vessels, or of cork, though they are very open; whereas oil, which is much thicker than the former, can hardly be retained in vessels of wood. Mercury does not easily pass through paper, linen, leather, unless squeezed; yet it consists of parts that are much more subtile than the pores of these bodies.

§. 1031. We must not easily give into the opinion, that bodies are quite opaque, which being grossly examined by us shall seem to be so. For there are fewer of this kind than one would imagine if they were tried in a dark place, and the sun were to illuminate them on one side. Who would imagine that the fingers of our hands are transparent like horn? which is true however, and the same is found in many other bodies.

^a Smith's Opticks. §. 587.

§. 1032. Any body we call a *speculum*, which is polished to such a surface, and endued with such a repelling force, that it regularly reflects the light that falls upon it; in what follows we shall conceive such specula to be of metal, or such as reflect the light back by it's anterior superficies.

Tab. 18.
Fig. 4.

§. 1033. If a ray of light AC falls upon a speculum, it is found that the angle of reflexion BCO is equal to the angle of incidence ACO .

§. 1034. Therefore the ray BC returns with the same force from the reflecting point C , wherewith it approached it. For the motion AC of the incident ray is resolved into AO , CO ; and whereas the motion AO , parallel to the speculum, remains unaltered, it will be $OB = AO$; but the ray impinges at C with the motion OC , which if it did not continue at the return, it could not be $CO = OC$, and then it would not be the angle $BCO = ACO$. But the equality of these angles is known by observation, and therefore the force of the returning ray is the same as of the incident ray.

§. 1035. The reflected ray CB lies in the same plain with AC , which is perpendicular to the reflecting plain DCE .

For AB being drawn, a triangle ACB is formed by the incident and reflected ray, which is always in one plain. But because the motion AC is conceived as resolved into AO parallel to DCE , and into OC perpendicular to it; every plain that passes through OC will be perpendicular to DCE .

§. 1036. The passage of the ray AC falling upon the plain speculum DE , and reflected by it into CB , is the shortest.

For suppose the ray to be incident at F or f, and to be reflected to B. Then $AF + FB$ or $Af + fB$ will be longer than $AC + CB$. Let AC be produced to P, that CP may be equal to CB , and draw the right line PB . It will be $AC + CB = AC + CP$, and the angle $ECB = ECP$, and therefore $BCF = PCF$. Hence the side $FB = FP$. But $AF + FP$ are greater than AP , and therefore $AF + FB$ greater than $AC + CP$, which are equal to $AC + CB$; after the same manner $fB = fP$. But $Af + fP$ are greater than AP , and therefore $Af + fB$ are greater than $AC + CB$. This proposition is not universally true in curved specula^a.

§. 1037. The position of the eye being given at E, and of the object A, from the given speculum BF, to find the point C, from whence the ray AC proceeding, is returned to the eye in CE. Tab. 18.
Fig. 5.

From A and E let fall perpendiculars upon the speculum at B and F, and let AF and EB be drawn, which cut one another in D. From D let fall the perpendicular DC, and drawing AC and EC, AC will be the incident, and EC the reflected ray. For it is $AB \cdot FB :: DC \cdot CF$; and $EF \cdot BF :: DC \cdot BC$; therefore $AB \times CF = BF \times DC = EF \times BC$; therefore $AB \cdot BC :: EF \cdot CF$; and the two triangles ABC and EFC will be similar, and the angle $ACB = ECF$. Or let AB be produced to K, till $AB = BK$, and the right line ECK being drawn, the point C will be that required.

§. 1038. The image LM of an object DE, that is placed before a plain speculum AB, ap- Tab. 18.
Fig. 6.

^a Smith's Opticks, Rem. p. 70.

appears to a spectator CH to be at the same distance behind the speculum, as the object is distant from the speculum. Secondly, the image LM is like and equal to the object DE. And thirdly, it is in the same situation in respect of the eye as the object is.

From the point of the object D rays are emitted upon the whole superficies of the speculum, of which DF and DG, with all that are intermediate, are reflected in FC and GH, and enter the eye. As from the lowest point of the object E, only the rays EN, EO, with the intermediate, after reflexion are brought back in NC, OH, and enter the eye. These produced backwards CF, GH, meet in L, and CN, HO produced backwards meet in M, and let the right line DL be drawn. The angle DFA = CFB = IFL, and therefore DFG = LFG. But the angle DGA = HGB = LGA, and the side GF = GF; therefore the triangle LFG = DFG; because the angle DFI = LFI, and the sides LF and FI are equal to the sides DF, FI, it will be LI = DI. Also drawing ME, it will be shewed in the same manner that the right line ZM is equal to ZE; therefore the image is as far distant behind the speculum as the object is before it. Secondly, because the angle DFB = LFB, and EOA = MOA, FO = FO, LF = DF, MO = EO, it will be LM = DE, and therefore the image is equal to the object. And thirdly it will be in the same situation in respect of the eye.

§. 1039. Therefore to a spectator that stands before a plain speculum, the right parts of his body will appear at his left, and on the contrary. Secondly, if the spectator shall approach towards the speculum, or retire from it, the image will

seem to approach as much towards the speculum, or to withdraw from it.

§. 1040. If the plain speculum CD lies parallel to the horizon, and the object AB is perpendicular to the horizon, it will seem to a spectator in O inverted, as ba. For the points of the object A and B ought to appear as far behind the speculum in a and b, as they are distant before it. The demonstration is the same as in §. 1034. Tab. 18.
Fig. 7.

§. 1041. If the plain speculum CD is inclined to the horizon in an angle of 45 degrees, a vertical object AB will appear horizontal to a spectator in OH, as in ab. But if the object ab is parallel to the horizon, to a spectator in oh it will appear perpendicular to it as is AB. The demonstration is the same as in §. 1034. Tab. 18.
Fig. 8.

§. 1042. If the glass speculum KBDE at its further superficies be covered with quicksilver, each of its surfaces will reflect light, so that the point C of an object will appear to a spectator OR by a double image A and a; one of which A, which is the remoter, will be reflected by the anterior surface of the speculum BE, and the other a, which appears nearer, is returned by the posterior surface KD, and is seen by means of the rays refracted at their coming out of the glass, and causing the image a to appear nearer to the eye. This double image is best perceived if a lighted candle is placed before the speculum, and the spectator sees it by rays obliquely reflected; as also if the glass be pretty thick. If the speculum be viewed very obliquely, the candle will appear not only double, but multiplied six times or oftener; because some of the rays reflected by the posterior surface of the glass to the anterior will pass out of the speculum, Tab. 18.
Fig. 9.

lum, but others that are not so strong will be again reflected by the anterior surface to the posterior, some of which being reflected to the anterior will go out, and exhibit another image; and some again will be reflected by the posterior surface. These repercussions at the two surfaces, and passages out at the anterior, will be repeated a number of times, till at last so few rays will pass out at the anterior surface, that they will not be strong enough to make a visible image.

Tab. 18.
Fig. 10.

§. 1043. If two plain specula AB , AC , are joined at right angles BAC , the object S will be seen once in the speculum AB , and twice in AC , by a spectator having his eye in X , between the speculum AC and the right line AO , that bisects the right angle.

For the ray SE emitted from S , after one reflexion at the point E , comes to the eye X ; therefore the image of the object will be seen behind the speculum AB . But another ray SD is reflected to F , from whence it is sent back to X . Another ray SM proceeding from S is reflected from M to X ; therefore a double image of the object S will appear behind the speculum AC .

§. 1044. If the two specula AB and AC contain an acute angle, and the object R be placed in the right line AR that bisects the angle, an eye in X , between the speculum AC and the right line AO , will see the object multiplied, because of the different reflexion of the rays, from one speculum to the other. Thus if the angle BAC be 65 degrees, the eye in X will see the object five times in the specula, twice in AB , three times in AC , and lastly the object itself.

If the angle be 60 degrees, the object will be seen, and 6 times also in the specula.

If the angle be 50 degrees, the object will be seen 7 times in the specula. If it be 40, it will be seen nine times. If it be 36, the object will appear 10 times repeated; and if it be 30 degrees, it will be seen 11 times in the specula. And thus it will still be oftener repeated, the more acute the angle is which is contained by the specula.

§. 1045. If two specula CB and ED are parallel to each other, between which is the object A on one side, and the eye O on the other, there will be seen a series of images, that proceed *in infinitum*. Tab. 18.
Fig. 11.

Let the right line KH be drawn perpendicular to each speculum. Take $DF = AD$, and draw the right line FMO, as also AM. The image of the object A will appear at F; for the angle $AMD = DMF = EMO$.

Let AG be taken double to the distance of the two specula; draw GPO, and $BI = BA$, as also PI. The object A will appear at G by means of the reflected rays AN, NP, PO; for in the two equal and similar triangles BNI and BNA, the angle $BNI = BNA$; also $DI = DG$, for $AG = 2BA + 2AD$: hence $DG = 2BA + AD$. But it is $DI = 2AB + AD$, and therefore $DG = DI$; whence the triangle $IPD = DPG$, and the angle $IPD = DPG = OPE$; and therefore OP is the reflected ray from PN, which is also reflected from AN, so that the image will be seen in G.

Then let FH be taken equal to twice the distance of the specula, and let the right line HO be drawn, which may cut ED in S. Make $BL = BF$, and the two triangles RBL and RBF will be equal and similar; whence the angle $LRB = FRB$. But $DL = DH$, because it consists of $BL + BD$, to which DH is equal. Hence the triangle LSD is equal to HSD, and the angle

L 2

LSD

$LSD = HSD = OSE$; wherefore the ray OS is reflected from RS , which is the reflected ray from RQ , which again is reflected from AQ , and therefore the object A will be seen at H .

And thus we may still go on; so that it is plain the object A may be seen multiplied, or often repeated, by the eye of a spectator at O .

§. 1046. From what has been now delivered we may understand the construction of a polemoscope, and of other catoptrical machines, which have been treated of by *Dechales*, *Wolffius*, *Smith*, who may therefore be consulted. The following is a polemoscope. In the tube $KNDM$ open at A , a speculum AB is placed obliquely, and another speculum CD is fixed parallel to it. At E is a perforated canal, at which the eye is applied; therefore external objects S will project rays upon the speculum AB at F , which will be reflected at equal angles to P , and thence to E . So that an eye placed here may see the objects S . In a manner like to this a reflecting telescope is composed.

Tab. 18.
Fig. 12,
13.

Tab. 19.
Fig. 1.

§. 1047. If rays of light AX , CK , fall upon a convex spherical speculum $NKXP$, parallel to it's axis XB ; these being reflected will diverge from the speculum, and will form an imaginary focus in E , which is the middle distance between the center of the speculum F , and it's superficies KX .

Let there be two rays AX and CK , which are very near to each other. From the center F , through the point of incidence K , let the right line FKL be drawn, which will be the cathetus; also the right line EKM . Then MK will be the reflected ray if CK be the incident; for $EF = EX$. But $EK = EX$, because the rays are very near; therefore $EK = EF$. Hence in
the

the isosceles triangle the angle $EKF = EFK$, to which CKL is equal, because of the parallels CK , XF , and $MKL = EKF$; therefore $CKL = MKL$.

§. 1048. If the diverging rays EB , ED , fall upon the convex spherical speculum BD , the imaginary focus will be in C , if there be taken $AC . CB :: AE . EB$.

From the centre A through D let the cathetus Tab. 19. ADR be drawn. Then centre E , radius ED , Fig. 2. let an arch be described cutting the cathetus in R , and let ER be drawn. Through D let there be drawn CDN parallel to ER , and C will be the point required. For because of the little arch BD , it is $CD = CB$, and $EB = ED$; therefore $AC . CD :: AE . ER$; or $AC . CB :: AE . EB$. But the angle EDR is the angle of incidence, to which in the isosceles triangle the angle ERD is equal. But because of the parallels ER , DN , the angle RDN is equal to it; therefore DN will be the reflected ray of the incident ray ED .

§. 1049. Because it is $AE . EB :: AC . CB$, by compounding it will be $AE + EB . EB :: AB . CB$; and therefore the greater the ratio of $AE + EB$ to EB , so much the greater ratio AB will have to CB ; wherefore if the radiating point E approaches nearer to the speculum, the imaginary focus C will also approach nearer. And the object being placed in B , the image will be also in B , that is, in the surface of the speculum. Also the point C will be thus found; because it is $AE + EB . AB :: EB . CB$; let F be the focus of parallel rays, then by taking half the former ratio, it will be $EF . FA :: BE . BC$.

§. 1050. If from a point of the object E we
L 3
conceive

Tab. 19.
Fig. 3.

conceive many rays to fall upon the superficies BDS, and to be thence reflected; let them all be continued backwards, and by their intersections they will form a curve CCC, which they will all touch; and the rays will seem to proceed from this curve, to an eye placed without the speculum, and therefore the image of the object E will appear in this curve.

And the object E being moved about the speculum, the curve CCC will move in the same manner, and therefore the object will always appear erect.

Tab. 19.
Fig. 4.

But because the object, as far as it can be seen, is seen in a portion of this curve CCC, it will appear to be diminished, as in this scheme; in which EF the object from the point E emits the rays EB, EG, with intermediate ones, and are reflected by the speculum to the eye DH, which continued backwards seem to have proceeded from the point I, and the rays FM, FN, with the intermediate ones continued backwards, seem to proceed from the point L; wherefore the whole object EF, diminished near the speculum in IL, is seen in an erect situation, and something out of shape.

Tab. 19.
Fig. 5.

§. 1051. If the speculum is spherico-concave ZBDH, upon which parallel rays fall AB, ED, that are but little distant from one another, and of which AB passes through the center of the speculum; this being reflected will meet in the point C, intermediate between the center of the speculum A, and it's superficies ZBD.

For the ray AB falling perpendicular at B, returns the same way. From the center of the speculum A let the cathetus AD be drawn; the angle of incidence of the ray ED will be EDA, to which the angle of reflexion CDA must be equal;

equal; because BD is a small arch, it will be $CB = CD = CA$. Therefore the triangle ACD is isosceles. And since the angle $CAD = EDA$, it will be $CDA = EDA$. Therefore the point C will be the focus, or the point of concourse of the rays.

But if the ray GH shall be farther distant from the axis AB , drawing the cathetus AH , CH will be a good deal bigger than CB ; and therefore the angle CHA will be less than CAH . The incident ray GH will not be reflected in HC , but will cut the ray AB between C and B ; wherefore such rays as are more distant from the axis AB will form a small circle upon the plain, which would be perpendicular to the axis AB in C . This little circle seems intirely to be formed by the sun's rays falling upon the superficies of the speculum, and is called a focus, of which we have mentioned the effects in §. 578, 579.

§. 1052. If the radiating point be placed in the point C , which is intermediate between the center of the speculum A and it's superficies, it's light will be reflected in parallel lines DE , HG , because of the equality between the angles of incidence and reflexion. Hence the great use of this kind of specula, to project the light to a great distance.

§. 1053. If the radiating object be placed in the center A of the speculum, all the rays will fall perpendicularly upon it, and therefore will return to the center A . Wherefore if the eye be placed in the center, it will receive all the rays emitted from every point of itself; therefore every point will appear of the same magnitude as the superficies of the speculum, and in the same place; so that nothing can be seen distinctly.

Tab. 19.
Fig. 6.

§. 1054. If the radiating object E be put beyond the center A of the speculum, and diverging rays EB, ED, very near to one another fall upon the speculum; the concurrence of the rays will be at C, and it's distance CB from the speculum will be to CA, it's distance from the center, as BE, the distance of the object from the speculum, to EA, the distance of the object from the center.

For since BD is a small arch, it will be $EB = ED$, and $CB = CD$. But because it is supposed $CB . CA :: BE . EA$, it will be $CD . CA :: ED . EA$, or $CD . ED :: CA . EA$. Therefore the angle $CDA = EDA$. But EDA is the angle of incidence, and therefore CDA will be the angle of reflexion.

Because $BE . EA :: CB . CA$, it will be *componendo* $BE + EA . EA :: CB + CA . CA$, and *permutando* $BE + EA . AB :: EA . CA$. And taking half the former ratio (making I the focus of the parallel rays) it will be $EI . BI :: EA . AC$. This is the same rule as was given in §. 1049, and is hence universal. Therefore the point C will be the focus of the rays proceeding from E. And an eye placed in this focus will see an object in like manner as in §. 1053.

The rays emerge diverging from this focus C, as CG, CH, and therefore an eye placed in GH will see the object E as if it were in C, and also inverted.

But if the radiating object is placed in C, it's rays reflected by a speculum will meet in E; wherefore the object will there be represented in the air, which will be seen inverted in E, by an eye placed beyond E.

§. 1055. If an object E be placed within a fourth part of the diameter of the sphere, of which the speculum is formed; the distance CB of the imaginary focus from the speculum, is to the distance CA of this focus from the center of the speculum, as the distance BE of the object from the speculum, to the distance EA of the object from the center of the speculum. Tab. 19.
Fig. 7.

Let the ray ED be incident, and the cathetus AD be drawn, and ER parallel to CDN. Because of the small arch BD, it will be $EB = ED$, and $CB = CD$.

In the two similar triangles AER, ACD, it is $AE . ER :: AC . CD$. It is supposed that $AE . EB :: AC . CB$. And because $CB = CD$, it will be $AE . EB :: AE . ER$. Therefore $EB = ER = ED$. Hence ERD is an isosceles triangle. But the angle $ERD = ADN$; therefore the angle of incidence EDR is equal to the angle of reflexion ADN, and the point C is the imaginary focus.

Now because $CB . CA :: BE . EA$; it will be *componendo* $CB + CA . CA :: BE + EA . EA$; and *permutando* $CB + CA . BE + EA :: CA . EA$; and taking half the terms of the foregoing ratio (supposing the focus of the parallel rays to be in I) it will be $CI . IA :: CA . EA$.

§. 1056. If the object EF be placed at the distance from the speculum AC as in §. 1055, and the eye shall be at the same, a less, or a greater distance from the speculum; it will always see the object EF in the place determined by §. 1055, or behind the speculum at HM, enlarged and erect. For right lines being drawn from the center of the speculum P, by the confines of the object, to the place found behind the speculum, Tab. 19.
Fig. 8.

Tab. 19.
Fig. 8.

as PEH, PFM; the same image HM will be seen by means of the rays EBD, EBH, FOD, FCH.

Our design will not permit us to pursue and demonstrate all the phenomena, which a speculum of this kind would exhibit. That such specula were not unknown to the ancients, appears from *Seneca*, *Quest. Nat. Lib. I. cap. 16.*

§. 1057. A cylindrical convex speculum may be conceived as consisting of portions of equal circles, placed directly to one another, so that a right line may conjoin all their centers. Therefore a section of this perpendicular to the axis will not differ from a section of a sphere through the center. So that some of those things we have already delivered about the spherically convex speculum will obtain here also. Or on this account objects will appear less, behind the speculum, and erect. But as a section of a cylinder parallel to the axis is as a section of a plain speculum; therefore the phenomena of a cylindrical speculum must also be considered in respect to this. Therefore objects on the first account will appear diminished or contracted, but not on the latter: And they will seem to be in other places behind the speculum, and more deformed on this account.

Yet deformed images may be drawn, which being inspected by means of this speculum, will again be restored to regularity. But how such are to be drawn, an anonymous *French* author has very well instructed us^a, who has professedly treated of many kinds of specula.

§. 1058. A concave cylindrical speculum may be considered as compounded of mere equal circles lying upon one another, and therefore it will

^a La Perspective pratique, par un Religieux de la Compagnie de Jesus.

exhibit phenomena like to those we have mentioned about the spherically concave speculum. For in this the objects will be seen enlarged, erect, inverted, and in several places. But as it's section the other way would be a right line, as that of a plain speculum, on this account the phenomena will be as in a plain speculum. Wherefore the images of objects will become very much deformed.

§. 1059. But chiefly pyramidal and conical specula exhibit wonderful phenomena, which evolve as it were and restore most intricate and deformed images. Let ABC be such a speculum, and the deformed object surrounding it on all sides, as part of it is represented at CG, and the eye at O; therefore a ray proceeding from a point of the object D, and reflected by the speculum at P, is brought to O, and seems to proceed from i; so the ray of the point E, reflected to O from the point of the speculum S, is seen at k; the ray FV returning from the speculum is seen at m, and the ray GB at n. Therefore the external parts of the object will be seen to constitute the internal parts of the image, and the internal parts of the object will make the external parts of the image.

Tab. 19.
Fig. 9.

§. 1060. By means of the pyramidal speculum placed in the square X, the parts of an object drawn in triangles A, B, C, D, separated from one another, seem to cohere in a continued image.

Tab. 19.
Fig. 10.

§. 1061. Nor are those phenomena less surprising, which are exhibited by a prismatical speculum ABCDE. For when the parts of an object are cut asunder between SAR B, as also MBLC, NCOD, QEPD, by an eye placed in F they are seen to constitute an intire image of the object.

Tab. 19.
Fig. 11.

§. 1062.

Tab. 19.
Fig. 12.

§. 1062. From the foregoing doctrine it will be easy to understand the reason of several machines, partly dioptrical and partly catoptrical, among which is the *portable camera obscura*. For let AB be the object, and CD a spherical convex lens; the rays emitted from the object AB upon the lens, and refracted, will meet in GE, and there paint the image. Wherefore if there is any plain there, as a paper, or a glass speculum unpolished on one side, but polished on the other; to a spectator S the object will appear painted upon EG, but inverted. But if we chuse to have it erect, let a plain speculum HK be put at half a right angle at the base of the machine. This will reflect the rays transmitted through the lens, so that the image of the object will be painted at NM. Therefore the unpolished glass placed here will receive the image, which will be seen erect by a spectator P.

Tab. 20.
Fig. 1.

§. 1063. Also the *megalographick* or *magick lantern* (as it is usually called) affords very pleasant spectacles, which was invented and described by *Kircher*, and improved by others since. In this C is the flame of a candle or lamp, radiating nearly in the center of a spherically concave speculum AB, which reflects the light to the lens DD, which therefore receives the light from the anterior and posterior face of the flame, and by refraction disposes it, so that all of it may fall upon a picture painted upon the glass EE, such an one as we shall have a mind to represent. The light emitted from every point of the image EE, diverging and falling upon the convex lens G, is there refracted that it may become converging, and so falling upon another lens H, by the refraction of this is made more converging. And whereas the rays intersect one another at L and K, an

K, an image is painted upon a white plain KL, but inverted and very much magnified.

Instead of the flame C *Kircher* made use of the sun with very good success; nor is the lens DD then necessary. And because at all times of the day we cannot always receive upon the picture EE the rays emitted from the sun directly, instead of DD we may substitute a paper besmeared with oil of turpentine, through which the sun's rays being transmitted, will equably illuminate the picture EE.

§. 1064. Before in §. 1023 we mentioned *Newton's* catadioptrical telescope. This being something improved by the ingenious Mr. *Hadley*, is now a most excellent invention, as being but of a small length, yet represents very remote objects greatly magnified, most distinctly and plainly. So that one of a foot long has the same effect as a dioptrical telescope of 12 or 14 feet long; nay, if it be 6 or 7 feet long, it performs as well as a dioptrical telescope of 100 feet long. Let ABCD be a large tube, at the bottom of which Tab. 20. BC is put a spherico-concave metalline speculum Fig. 2, 3. GH; the rays EG, FH, emitted from a remote object PR, somewhere intersect one another, so that EG, eg, come from the inferior part, and fh, FH, from the superior part of the object; these entering into the tube, which is open at the upper end, and falling upon the speculum GH, are reflected converging, and would meet at mn, there to paint the image. But before they can effect this, they fall upon the small plain metalline speculum KK, by which they are reflected to the hole at the side L, intersecting one another at qS, and there describing the image qS. At the hole L is put a spherical convex lens, whose focus is S. This refracts the rays, so
that

that those which proceed from the same point of the object become parallel; but those which are emitted from the extreme points of the object, converging towards one another enter the eye O, which beholds the image Sq as an object through a microscope L. Hence the object will appear magnified, inverted, very bright and distinct; but it seems enlarged in respect of the simple view, as is the length of the focus of the speculum to the length of the focus of the lens, or as AI to II.

Tab. 20.
Fig. 9.

§. 1065. James Gregory has also treated of catadioptrical telescopes; and has added a conclusion to prop. 59. of his *optica promota*, in which taking notice of three kinds of telescopes, dioptrical, catoptrical, and catadioptrical, he thus speaks of this third kind. *This excellent kind has no inconveniencies, and may have all the properties of the other kinds, if the lenses and specula are rightly disposed.* Yet the author confesses, that these telescopes were attempted without success; but in the year 1726 Mr. Hadley brought them to perfection by making a small change. TYMZSSNYT is a tube, in which is a spherico-concave metalline speculum perforated at X; before at EF is a lesser spherico-concave speculum, fastned to a moveable branch RT. Let AB be a remote object, from whose upper part A proceed the rays cd, CD; and from the part B proceed the rays il, IL. These intersect one another before they enter the tube. The rays falling upon the speculum LD meet in the focus KH, painting here an inverted image; they proceed farther, and fall upon the speculum EF, whose focus would be in f; reflected by this they would meet near SS, and paint another erect image; but a lens is placed at MN, causing them, by it's refraction,

Tab. 21.
Fig. 1.

to meet sooner at P V, and there exhibit an image, which by the meniscus S S is seen magnified and erect at O. The magnitude of the object seen through the telescope, is to that which appears to the naked eye, as the angle T O S, to the angle b G A. We have exhibited the external apparatus of this telescope in Tab. XXI. Fig. 2. Tab. 21.
Fig. 11.

And thus we have given a few strictures, in which are contained the first principles of opticks. As to the more sublime parts, they may be found in *de Chales's Mundus Mathematicus*, *Barrow's Optical Lectures*, *Huygens's Posthumous Works*, *James Gregory's Optica Promota*, *David Gregory's Dioptrick and Catoptrick Elements*, *Molyneux's Dioptrica Nova*, *Newton's Opticks and Optick Lectures*; but especially in *Dr. Smith's Compleat System of Opticks*, who has gone beyond all the rest in this science.

C H A P. XXXVI.

Of the Air.

§. 1066. **T**HAT fluid, invifible, intangible, transparent, elastick, sonorous body, which every where furrounds our earth, we call the *Air*. By the ancients it was called *Spirit*, because of it's subtilty, though it be really corporeal. It appears that the earth is on all fides furrounded by this animating inspirable matter, because wherefoever men have refided, they have inspired and refpired air, have observed clouds fufpended in it; alfo the fea to be moved by it, which of itfelf is languid and quiet, and that it refifted bodies however moved in it. All which things

things the air could not perform, unless it were a body.

§. 1067. The whole air surrounding the earth, together with all the bodies floating in it, is called the *terrestrial atmosphere*.

§. 1068. This is composed of vapours, exhalations, or of the most subtile and volatile parts of all earthly bodies, as well solid as fluid; as also of fire, whether of the sun, of the stars, of burnt earthly bodies, or of subterraneous fire breaking out and ascending upwards.

§. 1069. But that which is properly the air is a fluid of it's own kind, distinct from vapours and exhalations, and to be known by it's proper characters, though now it is blended with the particles of all sorts of bodies. For first, air shut up in vessels of glass or metal always remains the same without change; but it is not so with vapours; because as soon as they grow very cold or freeze, they lose their elasticity, stick to the sides of the vessel, become fluid again, return again into a mass. So that vessels, which before were quite full with this elastic vapour, are found almost empty. Also the exhalations of other bodies in process of time are destroyed as it were, when losing their elasticity the parts are conjoined, and constitute a fluid mass; as appears from many of *Boyle's* experiments^a, made on the factitious air of grapes, of paste made of flour, flesh, and other things; as also from some of *Dr. Hales's* experiments^b. Secondly, air has a power of nourishing earthly fire in combustible matter, whereas vapours and exhalations very soon extinguish fire, the most vivid flame, or the bright-

^a Continuat. Exper. Phys.

^b Vegetable Statics, Exp. 83. Haemastatics, App. Exp. 2.

ness of burning coals, as also of red hot iron; as the learned Dr. *Halley* has observed; and likewise Dr. *Hales*^a, in air generated by antimony and an affusion of spirit of nitre. Hence in the *Grotta de Cani* in *Italy*, and in the quarry of *Pyrmont*, burning torches held near the ground are immediately extinguished, though it expires sulphureous spirits; as *Misson*^b has observed, and *Scipione*^c. Fermenting wine emits a *gas sylvestre* from the bung, which will extinguish a burning candle^d.

Thirdly, air inspired by animals is as it were the cause of the continuance of life and health; whereas *in vacuo* almost all animals instantly perish. But all kinds of vapours and exhalations are very injurious to the respiration and life of animals, that it is not safe either for man or beast to suck them in, nay, they can hardly take in a more deadly poison. This is plainly manifest of the exhalations of burning sulphur. Hence in the *Grotta de Cani* and quarry of *Pyrmont*, as also in a pit dug in the *Isle of Wight*^e, the sulphureous spirit that exhales from the ground is the occasion of the quick destruction of animals. The exhalations of red hot brass^f soon kill animals, as also those of charcoal, the coals of *Holland* turfs, burning spirit of wine, oil of turpentine inflamed^g, burning of green oak wood, do the same; as also the vapour of fermenting wine or beer^h. How

^a Haemastatic. App. Exp. 3. p. 215.

^b Itinerar. Italic.

^c Philos. Transf. No. 448.

^d Newman de Vino. p. 365.

^e Philos. Transf. No. 450.

^f Hauksbee Phys. Mech. Exp. 11.

^g Hales's Vegetable Staticks, p. 170.

^h Camerar. in Epist. Taur. p. 31. Newman de Cerevis. p. 280.

often have new vapours, bursting out of caverns, been fatal to the labourers? or the air in old wells, corrupted by vapours that have stagnated for a long time?

Fourthly, the intension or elasticity of the air is in a determined and constant proportion, that is, as the density; and it occupies spaces which are in a reciprocal ratio of the compressing weights. But it is not so with vapours and exhalations, a few excepted; for I have observed the elastick vapours of paste, when compressed by a force as big again, to be reduced into a space four times less. *s' Gravesand* observed a bubble in water, which was expanded into 15000 times a greater volume, when the elasticity of the air was diminished only 300 times^a. Yet I must own that there are such things as constant elastick exhalations, and of the same degree of condensability as the air itself, such as the ingenious Dr. *Hales* has described^b, which were preserved by him for the space of 6 years, and of the same elasticity as the air. But such exhalations are very rare.

Fifthly, if the air was not some fluid different from exhalations and vapours, why does it continue after thunder and rain? For then the exhalations are inflamed, which together with the vapours fall upon the earth in the form of rain. But the air is observed only to be more purified after it has rained. Therefore it is something distinct from exhaled bodies, which God has created at the same time as the earth, that by it's weight and other properties it might immediately be the cause of the vegetation of plants, as also of the life of animals as soon as created. Neither

^a Instit. Philos. §. 655.

^b Haemastat. App. p. 320.

is it produced of water turned into vapour, as some Philosophers have thought*.

§. 1070. When air is collected in any notable quantity, it has always been observed to preserve it's fluidity. Neither by being long kept in vessels, nor by the intense natural cold of northern climates, nor by artificial freezing by means of spirit of nitre and ice, nor by any degree of compression can it ever be reduced to a firm mass. It's fluidity is great, because it's particles are very rare, spherical, moveable, light; nor do they attract one another by a great force, so that they are easily removed one from another.

1071. The air has no small gravity, nor when freely committed to itself would it ever depart from the center of the earth; as was said to be done by light things, according to the opinion of the *Aristotelians*, from a principle of levity. As for *Aristotle* himself, he allowed gravity to the air, which *Galileo* was the first that proved, and *Torricellius* and *Mersennus* confirmed, and now is demonstrated by a multitude of experiments. For first if the air be exhausted out of the receiver, the upper part being opened, it immediately rushes in again, descends through the aperture, and fills the vessel. If the air had levity this descent could not happen.

Secondly, the air presses with a great force upon bodies on which it incumbs; so that if a glass ball, or a thin piece of lead, is laid upon the receiver from which the air is pumped out, it will be squeezed or broke by the weight of the incumbent air upon the receiver.

Thirdly, vessels that are spherical or arched,

* Cic. de Nat. Deor. Senec. Vossius de mot. Mar.

when laid upon the plain of the air-pumps, when the internal air is drawn out, will be pressed down to the plain by the weight of the incumbent atmosphere.

Fourthly, hollow copper hemispheres laid on one another, and deprived of their internal air, will be squeezed to one another very strongly by the external air, so as not to be parted but by great violence.

Fifthly, we prove the air to be heavy very evidently, by bringing it's weight to the balance. For let a phial full of air be weighed, this will be lighter when the air is extracted; and heavier when it is let in again. But a suspicion may arise, that all the weight is owing to a mixture of vapours and exhalations. It is very certain that part of it's weight must be derived from them; for in a moist season, if air pass through very dry wood-ashes into an empty vessel, which with it's air is first weighed, it will not have the weight as before. But if this experiment is made in clear weather, the air that has passed through an alkaline salt is of the same weight as before it passed through. Now if pure air is not heavy, how can clouds float and hang suspended in it? For as these are heavy, if they were supported by no heavy body they must sink down immediately.

§. 1072. The specifick gravity of the air, when compared to that of water, has been sometimes observed to be as 1 to 800. But this is not constantly so, because the weight of the air is continually changing, according to it's different purity, density, and heat. In some places of *Europe* the specifick weight of the air to that of water seems to be comprehended within the limits of 1 to 606, and thence to 1000.

§. 1073.

§. 1073. How much the atmosphere ponderates upon the bodies beneath it, may be examined by means of a tube of glass, which is shut close at the upper end, and open at the lower one, and filled with quicksilver; which is sometimes suspended in it to the height of 29 inches. The weight of this is *in æquilibrio* with the weight of the atmosphere. Now because water is about 14 times lighter than quicksilver, water might be *in æquilibrio* with that in the tube, or with the atmosphere, at the height of $33\frac{5}{8}$ feet. Therefore the atmosphere by it's weight presses bodies at the superficies of the earth, as if water were poured upon them to the height of $33\frac{5}{8}$ feet. This has been confirmed by the experiments of *Pascal* and *Boyle*.

§. 1074. Because air is fluid, it presses with equal force according to all directions, as much upwards as downwards, forwards, backwards, and obliquely. Therefore all bodies, though never so tender, which are surrounded by the air, being pressed every way equally, are not destroyed. It appears from the experiment of Mr. *Marriot*, that the lateral pressure of the air is equivalent to the perpendicular pressure. For if a phial CD be filled with water, and perforated in B, where it receives the tube EF open at both ends; it retains the water in the tube at A, at the same height with the hole B; therefore the air pressing downwards with the direction EA, does not operate more forcibly, than that which presses laterally at the hole B. Tab. 21.
Fig. 3.

§. 1075. A tube filled with mercury, and *in æquilibrio* with the weight of the atmosphere, in honour of the inventor *Torricellius*, who first discovered this instrument in the year 1643, is called the *Torricellian tube*, and by some a *baroscope*

or *barometer*. This invention contributed not a little to the advancement of natural philosophy in the last age. Now because there is a space left between the mercury and the top of the tube, which is void of the grosser air; the Philosophers had a great desire to know and examine, what would happen to bodies when placed in this vacuum. Wonderful phenomena were here observed; and the difficulty of effecting this gave occasion to the invention of another machine, called the *air-pump*, by help of which the air may be easily exhausted out of any receivers.

§. 1076. That the mercury is suspended in the *Torricellian* tube by the weight of the incumbent atmosphere is thus proved; for if the tube be included in a long receiver, and the air is drawn out, the mercury will subside. But it will arise to it's former height if the air is admitted again.

1077. The *Torricellian* tube being fixed for a long time in the same place, the different altitudes of the mercury may be observed; which differences will be greater than what can proceed from the rarefaction of the heat of the atmosphere. This was observed first by *Torricellius* himself in the year 1645 or 1646. The least and greatest height observed in *Holland* was 27 inches 2 lines, and 30 inches; therefore the limits very nearly will be 3 inches. In the mean time it will be very certain, that the mercury will arise higher in the tube, when that which stagnates in the vessel is more pressed than before; and will descend when it is pressed less. And because the difference of the heights in the tube is 3 inches, this will be $\frac{1}{10}$ part in respect of the whole pressure, and of the greatest, which is equivalent to 30 inches; for it is $1 : 10 :: 3 : 30$.

§. 1078.

§. 1078. It may not be amiss to shew in a few words, from what causes it proceeds, that the mercury is pressed sometimes more and sometimes less. It will be pressed more when the atmosphere is heavier, which happens for these following reasons. First when more air is accumulated over any country, by winds blowing with a contrary direction, driving and gathering the air to an intermediate place; this therefore rising higher will make the atmosphere higher also. The winds seem to be the primary cause of changes in the atmosphere, and of the different heights of the mercury in the baroscope. For in regions lying between the tropicks, and in which an easterly wind always blows with the same strength, the mercury in the baroscope is hardly perceived to change, as the learned Dr. *Halley* testifies^a, both from his own observations, and from those of others.

Secondly, the atmosphere is also accumulated over our region, when the north wind blows, that cools and condenses the air. So that the altitude of the atmosphere decreases there, but the upper fluid flows hither on all sides, and by it's weight and quantity increases the pressure.

Thirdly, the mercury will also be higher, if the wind from the upper atmosphere is determined downwards towards the earth. For then it presses the air it meets in the same direction, and this presses the mercury in the same manner, as if it had a greater weight incumbent on it.

Fourthly, when the air is condensed by cold, the atmosphere descends, though it continues to have the same quantity as before; but for two reasons it will be endued with greater gravity;

^a Philof. Transf. N. 181.

partly because of a less centrifugal force of the parts, and partly because of their gravity increased. See §. 228 and 411. Hence it is that we find the mercury to be generally higher in winter than in summer.

Fifthly, when the atmosphere is impregnated with many vapours and exhalations, its gravity necessarily increases, as much as is the weight of those exhalations. Therefore if the air continues long to be at rest and without motion, it receives many vapours into it, and then the mercury is always found to ascend in the tube, as well in winter as summer.

§. 1079. The mercury will be less pressed if the atmosphere becomes lighter; and this may happen, if by impetuous winds, or by exhalations in effervency with one another, a part of the air be hurried away out of its place. Hence (as it were) a vacuum is made, into which the part above descends; yet nevertheless a less quantity of air will impend over that region of the earth. For which reason the quicksilver will descend, being less pressed in the tube, as is always observed during a storm. Nay, whenever you perceive the wind to blow with an increase of violence over the place of observation, you will find the mercury to descend at that instant, as *Hauksbee* also has demonstrated by an analogous experiment. When the wind ceases, the air again approaches to these places from all sides, because they contain less air of an equal density. Therefore because of the increase of the mass of air and its weight, the mercury will again ascend.

Secondly, the mercury descends in the tube, if the air be cleared of its exhalations and vapours, with which before it was plentifully impregnated.

pregnated. Hence at the time of rain the mercury is low in the tube.

Thirdly, when the winds blow upwards from the earth, they do, as it were, raise the atmosphere. Hence when some winds blow, the quicksilver is low in the tube.

Fourthly, if the air is rarified by heat, and the atmosphere becomes higher, although the same quantity continues, because of §. 228 and 411, yet it will have less pressure on the bodies below. Perhaps there may be many other reasons that are hitherto unknown, concurring to this effect. Now these I have mentioned may be very different in degree, and several of them conspire together, or oppose one another, on all which the different altitude of the mercury may depend.

§. 1080. From these circumstances well considered it appears, that the different altitude of the mercury in the tube does not foretel the future condition of the weather, but is only an indication of the present state of the atmosphere, or rather of it's degree of pressure upon earthly bodies. Sometimes from a certain condition of the atmosphere certain effects follow, which if they have been well observed, then a good conjecture may be made, whenever the same condition shall return. But this cannot be known from the pressure only, or from the height of the mercury in the tube; and therefore nothing certain can be concluded from that height alone, unless we discover the constitution of the atmosphere from several other observations and other circumstances. Wherefore no certain rules of prognostication can be delivered, as I am compelled to acknowledge, from the observations of many years carefully compared with one another.

§. 1081. The mutations of the mercury in the baroscope are greater in winter than in summer, and greater in cold than in hot places. First, because cool air is denser than warm or hot air, and therefore more adapted to the sustaining of many vapours. When the atmosphere is accumulated with these, it becomes very heavy, and very light when freed from them. Thus the winter months are observed to be often the most rainy.

Secondly, about the end of autumn, in winter, and at the beginning of spring, the most tempestuous winds and hurricanes rage: and the typhons, when in summer the air is more tranquil. Now the greatest changes of the atmosphere are brought about by the winds, and great portions of it are moved out of their places; whence becoming lighter, it presses the mercury in the barometer with less force. Also the winds accumulate the atmosphere, by condensing the air by it's opposite directions, which thence becomes heavier, and presses the mercury in the tube much more. Because in places near the pole the air in winter is most cold and dense, therefore both the alledged causes chiefly obtain there, and are the occasion, that much greater mutations happen by the pressure of the atmosphere, in the colder than in the warmer regions.

1082. Since the limits of the variations of the quicksilver in the tube are so narrow, Philosophers have contrived to enlarge them by several artifices, hoping they may thus observe the least alterations of the atmosphere. Hence Sir *Samuel Morland* constructed an inclined tube EDC, in whose part DC, which is longer than AB the limits of the changes in the vulgar baroscope, the changes must necessarily be greater in proportion

Tab. 21.
Fig. 4, 5.

tion to the length CD. This is a pretty invention, but labours under this inconvenience, that in this the surface of the mercury is not always level, as fg, but convex, as k hg; nearly like and parallel to the upper arch of the tube Z, so that the true altitude of the mercury cannot be observed. Beside the mercury incumbs too much on the side of the tube DC, so that it does not descend so readily as in the vulgar tube.

§. 1083. Mr. *Hooke* invented a tube ABDRGF, bending in it's lower part and open. In this is put an iron bullet G, which swims upon the mercury. A thread is tied to the bullet, which going round a pulley D, is stretched by another bullet H, when the mercury descends in AB, G is raised. Hence the prevailing little weight H by help of the thread makes the pulley D to circulate, which moves a long index LK, shewing the different degrees in the circle MNOP. This baroscope shews the greater changes of the mercury very well, but not the smaller changes so soon as the common baroscope. Not to mention some other inconveniences arising from the moist or dry air affecting the string, also from the friction of the pulley, &c. ^a.

Tab. 21.
Fig. 6.

§. 1084. In the year 1672 Mr. *Huygens* invented two kinds of barometers, the chief of which is this. To a tube OV, $25\frac{1}{2}$ inches long, bent at VP, on each side is connected a cylindrical vessel HR, CP, the diameter of which is ten times greater than that of the tube. Another tube CN hangs out of the vessel PLC. Let half of the vessel KO be imagined to be filled with mercury, as also the tube OMP, and half of the other vessel PL. Therefore if the mercury

Tab. 21.
Fig. 7.

^a Philof. Transf. N. 185:

shall fall one inch from K to R in the vessel KO, it will be raised one inch in P L from L to S, and then the whole column of mercury in the tube ROM will be two inches shorter, and only of the length RI, whereas before it was of the length KV. If therefore the change of the mercury in the common barometer shall be 3 inches, in this of Mr. *Huygens* it will be as little again; but half of the vessel LC, and part of the tube CN, is filled with water tinged with verdegrease mingled with spirit of nitre, that it may not freeze with cold, and covered over with oil of almonds, that it may not exhale. Therefore when the mercury descends in the vessel KO, it will drive the water out of it, and raise it in the tube. Now if it was without gravity, when the mercury in LC rises an inch, it would ascend in the tube to 100 inches; because their capacities are as the squares of their diameters. But since water is endued with gravity, which is $\frac{1}{14}$ part of that of mercury, 14 inches of water will be *in equilibrio* with one inch of mercury in height; therefore at least the change will be such as will be observed in the various altitude of this water. And $1\frac{1}{2}$ inch of mercury in each receptacle answers to 21 inches. And such a kind of baroscope will be very moveable, concerning which the author may be consulted *. But this machine has not much come into practice, because of some inconveniences. First, if oil be poured upon the liquor in the tube CN, it sticks to the sides of the tube and makes them obscure. Secondly, if oil be not poured in, the liquor flies off from CN. Thirdly, heat much dilates the liquor, which cold also condenses in CN, so that

* Journal des Scavans, An. 1672. p. 137.

the same quantity at a different height will be *in æquilibrio* with an equal weight of mercury. Therefore unless at the same time we have recourse to a thermometer placed near it, and composed of the same liquor; or unless we consult certain tables, in which the dilatation is set down, arising from the heat which the thermometer indicates, we can conclude of nothing certain.

§. 1085. Because Mr. *Hooke*^a did not think this barometer of Mr. *Huygens* to be entirely satisfactory, nor after him Mr. *de la Hire*^d; Tab. 21. they made it much more moveable, by joining to it another receptacle of the same diameter with the former. By this it is brought about, that as much as the mercury is raised in the lower vessel, so much the liquor is raised in the third vessel D N. Part of the lower vessel B C, and the tube C D, is filled up to the middle G with oil of tartar *per deliquium*; the other part of the tube G D, and part of the upper receptacle D K, is filled with a very light oil called *petroleum*. The other part of the machine B S A receives the mercury, as in Mr. *Huygens*'s barometer: When the mercury descends to half an inch from A to L, it is raised from B to H, and the petroleum as much from K to N; therefore there continues an altitude above the mercury $HN = BR$. Let the diameter of the tube C D be = 1, and the diameter of the vessels = 9: their capacities will be as 1 to 81. Moreover let the tube C D be above 80 inches long; and when the mercury ascends half an inch from B to H, the petroleum will be carried upwards from G to D the space of 40 inches.

^a Philof. Transf. An. 1686.

^d L'Hist. de l'Acad. Roy. An. 1708.

But

But when the mercury descends half an inch from B to R, the petroleum will descend 40 inches from G to I. Wherefore there will be in this barometer a remarkable motion of 80 inches, if the mercury in the vulgar barometer is only subject to a mutation of two inches.

This would be a very neat invention, if there could be had three fluids of a very different density, which would not stick to the superficies of the glass, nor mingle with one another, but whether ascending or descending would leave the glass, as quicksilver does. As these are not yet found out, we shall observe in process of time, that each of the oils stick too much to the superficies of the tube CD, so that it becomes dark; nor can we rightly judge of the true height of the terminating superficies G, because of the loss of the liquor that sticks to the sides. Also account must be had of the rarefaction of the liquors by heat.

Tab. 21.
Fig. 9.

§. 1086. In the year 1695 Mr. *Amontons* communicated the following invention to the publick^a. Let there be taken a conical tube AB, whose base B has an aperture not greater than $\frac{1}{12}$ of an inch. The mercury that can fill the upper part AC 30 inches long, shall also be in quantity sufficient to fill the lower and larger part of the tube DB, which is only $27\frac{1}{6}$ inches long. If the tube AB is 45 inches long, then when the common baroscope stands in it's highest station at 30 inches, the mercury in this tube will be between C and A; and if the mercury in the common baroscope be at it's lowest station at $27\frac{1}{6}$ inches, the mercury in this tube will be at DB. So that the distance between A and D is $17\frac{1}{6}$ inches. Therefore the mercury in this will have almost six times a greater motion than in the vulgar tube. This

^a Remarques & Experiences Physiq.

contrivance by some has been called the *marine barometer*, because the tube may easily be kept inverted at sea, and when it is inspected it may easily acquire the situation A B. But great care must be taken, that the least drop of mercury may not run out at the orifice B; because it's column being then lighter, it will no longer be *in æquilibrio* with the atmosphere, except in a place near the arch A. Secondly, too much attrition of the mercury will induce a great immobility. Thirdly, because the air will enter at the aperture B, and will apply it's moisture and salts to the sides of the tube, which will hinder the free descent of the mercury, retard it's ascent, and separate it into parts.

§. 1087. Mr. *Cassini*, and afterwards that excellent mathematician *John Bernoulli*, to a larger barometrical tube A B a little bending at it's lower part B H, added a small horizontal open tube C H, the length of which was so adjusted with it's capacity and that of the tube A B, that $2\frac{1}{2}$ inches of mercury from A B may fill the small tube from C to H. So that if the mercury is at it's highest station in D, in the small tube it will be at H. And if in it's lowest situation it is at L, in the small tube it will be at C. And since the tube C H may be of any length, provided the capacity of the larger one D L be increased, by this means a very moveable baroscope may be constructed. The attrition and attraction between the mercury and the tube C H make this barometer much more difficult of motion than would seem at first sight. Hence it shews very remarkably the mutations in the vulgar baroscope, but not the lesser changes.

§. 1088. Some Philosophers have given us other inventions and improvements, but not so celebrated

celebrated as these, and which the narrow limits of our design do not permit us to treat of. It is plain enough from all these, that the simple barometer is as yet the best for making accurate observations, if it be skilfully constructed. To this it is necessary that the mercury should be purged from all air, and that there may be none at all between the arch and the mercury. How this may be attained I have shewed in my physical dissertations.

§. 1089. The air by it's gravity produces several effects; for as it sustains the mercury in the tube to the height of 29 inches, so if a sucker be conceived in the tube put into the mercury, and raised upwards by withdrawing from the superficies of the mercury, and thus expelling the air; the mercury pressed by the weight of the atmosphere will necessarily enter the tube, and will adhere to the sucker as far as to the height of 29 inches. And though the sucker is raised higher, yet the mercury will follow it no farther, but will remain still at the same height. The reciprocal motion of the sucker will produce no farther effect, since it can only exhaust the air. Hence we learn, that in a pump, the water will not ascend higher than $33\frac{1}{2}$ feet, let the sucker be moved never so much. For at this height the weight of the water will be *in equilibrio* with the weight of the atmosphere. Therefore the water does not rise because it is sucked up, but because it is pressed by the air; for if the pump together with the water was included in a vacuum, although the sucker should be reciprocated, yet not a drop would rise; nor in a vessel that is close shut up, though full of water, can the pump take in any of it, however the sucker may be moved.

§. 1090.

§. 1090. The suction of an animal differs but little from the action of a pump; for the animal that sucks swallows the air out of it's mouth, shuts it's nostrils, takes the nipple on all sides with its lips, drives it's cheeks outwards, and makes a vacuum in it's mouth. The external air by it's gravity presses upon the breasts or udder, drives the milk that way where the resistance is taken off, thence to the nipple, and so into the mouth of the sucking animal. Of the same kind is the smoaking of tobacco: as also the action of the surgeons cupping-glasses. When these are fixed upon the skin, by help of a sucker or some other way, the air is exhausted, and therefore the glasses are squeezed to the flesh by the weight of the atmosphere. The humours are propelled to this cavity, by the afflux of which the place was swelled: also the air by it's gravity is the cause of our respiration.

Tab. 22.
Fig. 1, 2.

§. 1091. Among the effects which depend upon the weight of the air upon bodies, may also be reckoned the flowing of water through siphons of unequal lengths. Let such a siphon be EACD, full of water, and let it's shorter leg AE be put into the vessel B; the air by it's gravity will press the water upwards in each leg, which by it's gravity endeavours to descend; and with a greater force in the longer leg CD than in AE. Therefore there will be a greater ratio between the action of the air upwards, and the re-action of the water downwards, in the shorter leg AE than in the longer CD. And the water EA will be pressed upwards with a greater force than CD, therefore the fluid will ascend in EA, and drive out the remainder in AC, CD; because the same reason still exists, as long as any fluid is in the vessel B, it will continue to run out at the orifice D.

Tab. 22.
Fig. 3.

Tab. 22.
Fig. 7.

Tab. 22.
Fig. 3.

§. 1092. Some learned men have thought, that another cause different from the gravity of the air, produced this phenomenon; but that this is the true cause may be evidently demonstrated. Because if the siphon *EACD* be included in a receiver, out of which all the air is pumped, such as is the vacuum of *Torricellius*; (which thing may be effected, by filling the receiver quite full of water, all the air being first drawn out, and afterwards the water,) then in this vacuum there will be no running of the water through the siphon. Also the efflux of the water out of the siphon *EAD*, may be prevented, by closing up the orifice *C* of the vessel *BB*, and so hindering the pressure of the air. Or if the siphon *EACD* consists of two legs, the shorter of which *EA* exceeds 30 inches, and it be filled with mercury; then there will be no transflux of the mercury out of the shorter leg through the longer. But if a vessel also be placed at *D*, the mercury will leave the upper arch *AC*, and in each leg *AE*, *CD*, will remain at the same height, in which it is in the vulgar barometer. Or taking away the vessel *D*, the mercury will fall downwards which was before in *AE* towards the vessel *B*, and the rest will run out at the leg *CD*. But if the leg *AE* be shorter than the height of the mercury in the barometer, the mercury will pass through, which is a manifest token that the effect of the siphon depends on the weight of the air.

Tab. 22.
Fig. 8.

§. 1093. *Reisellius* has started a difficulty with his siphon of equal legs *EFG*^a; which is said to transmit water. For the orifices *E* and *G* lye in the same horizontal line, when water is

^a *Acta Lipsientia*, An. 1690. p. 142.

brought to the mouth G, there will be an efflux at E; and when water is brought to the mouth E, there will be an efflux at G. But such an efflux cannot be made, unless when the water that is applied to either of the orifices shall cause by it's altitude, that this leg shall become shorter, and the other longer. This will appear to any one, who carefully tries the experiment. By the help of this doctrine many effects that happen in nature may be easily explained. And many of the effects of art, as the artificial contrivance may be understood, by which *Tantalus* is made to drink.

Tab. 22.

§. 1094. Of all the properties of the air the chief is that which is called *elasticity*, because of some of it's effects analogous to those which we observe in elastick bodies. For by compression the air may be reduced into a smaller space, which compression ceasing, it restores itself of it's own accord to it's former volume. For let air be included in a pump, and let the sucker be forced down to the bottom, which may be done in some measure. The air will yield to the pressure, and will occupy a much less space than before. Then leave off to urge the sucker, and it will be drove out of the pump by the air, as it restores itself to it's former volume.

Fig. 4, 5, 6.

§. 1095. As in the foregoing experiment the air was squeezed into a narrower compass by the sucker; in the same manner the inferior air is pressed by the superior; so that near the surface of the earth it is in the same circumstances, as that which is pressed close in the cavity of a pump. Hence a small quantity shut up in a bladder, and put into a receiver, out of which the external compressing air is exhausted, will expand itself and stretch the bladder, just as if it were inflated and made turgid by the injection of a great quantity of air.

Tab. 23.
Fig. 9.

§. 1096. The air near the superficies of the earth is of such a quality, and dilates itself in such manner, that it's volume is in a reciprocal ratio of the compressing weights. This rule has been settled by *Boyle* and *Marriot* upon the following experiment. Let *AB* be a barometrical tube, which rightly prepared may suspend the mercury at the height *BC*. Into this let a quantity of air be admitted *AD*, and then the mercury will no longer be suspended at *D*, but will remain only at the height *BE*, and the air *AD* will expand itself into the space *AE*. The force by which the air of the atmosphere is compressed is equal to the weight of the atmosphere, with which the mercury at the height *BC* is *in equilibrio*; therefore the weight of the atmosphere may be expressed by the column of mercury *CB*. With this weight the air *AD* is compressed. But it is found by experiment, that this air expands itself into the volume *AE*, and therefore the remaining elasticity of the air so rarified, together with the weight of the mercury *CB*, are at equilibrium with the weight of the atmosphere, or with the column of mercury *CB*. Taking away therefore the column of mercury *EB*, the elasticity of the air in *AE* is at equilibrium with the remaining weight of the atmosphere, which is equal to the column of mercury *CE*; therefore the weight compressing the air expanded in *AE* will be as *CE*. Then if we measure the spaces *AD*, *AE*, possessed by the air in each case, they are found to be as *CE* to *CB*; wherefore the volumes of air will be in an inverse ratio of the compressing weights.

§. 1097. The same rule takes place also, when it is compressed into a less volume, as *Marriot* has well proved by the following experiment^a.

Tab. 22.
Fig. 10.

^a *Movement des Eaux*, p. 141.

Let there be a bending tube P O N M shut at M. Let a little quicksilver be poured into it, to fill up the lower part N O, so as to intercept the air in N M; which as it is compressed as much as the rest of the air of the atmosphere, may be conceived as pressed by the weight of the column of mercury C B in Fig. 9. Let mercury be poured into the tube P O, suppose to the altitude X O. The air in the leg N M will be compressed, so as to occupy only the volume M Z. Now the horizontal line Z F being drawn, the air M Z will be compressed as well by the weight of the atmosphere as by the weight of the infused mercury X F. Now measuring the spaces M Z and M N possessed by the air, and the compressing weights which are as C B and C B + X F, this proportion is observed to obtain M N. $MZ :: CB + XF . CB$. And therefore again these spaces, that are possessed by the air, are to one another in an inverse ratio of the compressing weights. I observed that when I reduced the air M N into a volume above four times less, that it did no longer comply with the given rule, but more strongly resisted the compressing forces, as the great *Boyle* likewise had formerly observed. And that the rule cannot always be constant appears from hence, that as soon as the particles of air touch one another, they must compose a mass that is entirely solid. Nor can they by any force in nature be reduced to a less volume, because body is impenetrable.

§. 1098. It is inquired, how far the air of the atmosphere, such as it is near the surface of the earth, is capable of compression? I can as yet perceive no limits; yet Mr. *Boyle* made it 30 times denser than it is. *Halley* tells us, that he had seen air 60 times denser. Dr. *Hales* by

help of a press condensed air into 38 times a lesser space^a. But by means of water condensed into ice, he reduced air into 1838 times less space than it possessed before, so that it was above as dense again as water; therefore since water is not condensable, the particles that compose air must be very different from those of water. For otherwise, if they could only be compressed into a volume about 800 times less, and then should be of the same density as water, they would resist all compressing forces whatever.

§. 1099. Because the elasticity of compressed air is *in equilibrio* with the pressing weight; that which is compressed by the weight of the atmosphere will re-act against this weight with an equal force. Therefore air shut up in a phial with mercury, in which is a tube with each end open, taking the air out of the tube, it will drive the mercury by it's elasticity out of the phial, to the same altitude in the tube as is that in the vulgar barometer: if in the mean time the air is not rarified.

But in any vessel if the air is made as dense again, it will be as much more elastick, and therefore in an open tube it may drive the mercury to the same height as it is in the baroscope: or instead of mercury, water beyond the height of 32 feet. So that very dense air shut up in a vessel DDBB, which is designed to compose an artificial fountain, will make the water A A B B to spout out to a great height. The water-spout of *Hero's* and *Niewentyt's* fountain depend upon air compressed, and so made more elastick. Hence also it may be understood, why air that is very much condensed in a wind-gun explodes a leaden

Tab. 22.
Fig. 11.

Tab. 25.
Fig. 2.

^a Haemastat. Append. p. 348. &c.

bullet with great violence, so that the effect it produces is hardly inferior to that of gun-powder. Tab. 22.

From the same principles may be explained the glass divers, *Sturmius's* fountain that obeys the word of command, and other the like phenomena. Fig. 12.

1100. The force by which particles of air repel one another, is in the reciprocal ratio of the distances between the centers of the particles.

Let there be two equal cubes XAE and ZBI , Tab. 22.
 which contain unequal quantities of air, so that Fig. 17,
 the distances between the centers of the particles 18.
 in XAE may be to those in ZBI , as 2 to 1. The number of the particles to be considered in the side DE will be to that in HI , as 1 to 2; and the same obtains in the side EG and IM , as also in DX and HZ ; therefore the number of the particles acting upon the surface DG will be to that in HM , as 1 to 4; and the number of the particles in the cube XAE will be to that in ZBI , as 1 to 8. The forces which act upon the equal superficies DG and HM , are as the forces by which the air is compressed. For the forces acting upon these superficies DG and HM , may be considered as compounded of the number of the acting particles, and the action of each particle; therefore this compound ratio ought to consist of the compounding ratio's which are in A to those in B , as 1 to 3. But the number of particles acting against the superficies DG , is to that against HM , as 1 to 4; and therefore the other compound ratio is necessarily as 1 to 2. But this is the ratio of the action of the several particles, and the distances of the centers are as 2 to 1; therefore this action of the particles in XAE will be to that in ZBI , as the distances of the centers of the particles in B to those in A .

§. 1101. The elasticity of the air being known, it may be understood, how it is exhausted out of receivers by means of the air-pump. For let us conceive the sucker to withdraw from the bottom of the pump, and that there is a communicating tube between this and the receiver. The air by it's elasticity will expand itself, and enter into the empty pump, till it is equally rarified in this and in the receiver. This air being expelled, and the sucker again removed from the bottom, which had been urged towards it for the expulsion of the air, by expanding itself the air enters again the pump out of the receiver, and this is done continually by the reciprocal motion of the sucker; so that by means of the pump it is more and more rarified perpetually; therefore by the pump the air can only be rarified, and not perfectly exhausted.

1102. This vacuum made by the pump is used to be called *Boyle's vacuum*; but it is not so perfect as the *Torricellian*, which is made in the upper part of the barometer, by the tube and the mercury.

§. 1103. *Otto Guericke* a German was the inventor of the air-pump about the middle of the last age, who made many fine experiments with it. These induced the great *Boyle*, with the assistance of *Gratorix*, *Hooke*, and *Papin*, to construct such a pump in *England*; with which making many useful experiments, he greatly improved natural Philosophy. Hence the machine is often called *Boyle's air-pump*. About the same time another was invented at *Leyden*, by the ingenious *Volder*, with which experiments were made in the year 1675, in the physical laboratory at *Leyden*. In our own time the learned *s'Gravesand* brought this engine to great perfection and simplicity, so that
by

by small labour and in a short time the greatest quantity of air may be pumped out of receivers.

§. 1104. That air may be rarified by being exposed to the fire has been taken notice of §. 775. And the elasticity is increased by which it endeavours to unfold or dilate itself every way. On the contrary, by cold it is condensed into a less volume, as if it had lost part of it's elasticity. The force of heated air is manifested, when being included in a thin glass phial hermetically sealed up, and exposed to a great fire, it so distends itself by rarefaction, as to burst the phial with a loud report^a. A bladder that before was not turgid, it so puffs up, as at last to burst it. But Mr. *Amontons* has made more accurate experiments concerning the force of rarified air^b. By these he has found, that a great or a small quantity being included in a vessel, acquired so much force by it's rarefaction, made by the heat of boiling water, that it was in proportion to the weight of the atmosphere, as 10 to 33, and sometimes as 10 to 35; which I have also sometimes observed. For the air thus heated was able to raise the mercury in the tube to the height of $8\frac{2}{7}$ feet, when the mercury in the barometer stood to 29 inches.

But when in the vessel it was made denser than that of the atmosphere, and it's force was examined after the same manner by boiling water, it was found to have the force of expanding itself in proportion to it's density^c. Thus it is with dry air. But no sooner has it received never so little moisture, but it acquires far greater force.

^a L'Hist. de l'Acad. Royal. An. 1710.

^b L'Hist. de l'Acad. Royal. An. 1708.

^c L'Hist. de l'Acad. Royal. An. 1702.

This does not depend on the air, but on the very great elasticity of the vapour; and therefore the event of Mr. *Amontons's* experiment is not always the same, at all times and in all places, but is subject to some variations.

§. 1105. But how much may air be rarified by fire? Mr. *Hauksbee* has observed ^a, that in *England* the expansion of the air from the limit of the beginning of freezing to the greatest summer-heat, is as 6 to 7. And in our climate we have almost the same proportion, unless that on a very hot day I observed something a greater expansion. The volume of air from the state of beginning to freeze, to the heat which is communicated to it by boiling water, is as 2 to 3. But Mr. *Bernoulli* has observed at *Petersburg*, the expansions of the air in hot water, in the hottest summer's day, and in the coldest winter's day, to be as 6, 4, 3. ^b The volume of air, like cold ice beginning to be formed, is to that growing hot in glass beginning to melt, as 1 to 3, provided the air be dry. For if it be something moist, it rarifies into a volume 12 times greater or more, than it had in the state of beginning to freeze. These experiments will perpetually differ, according to the different moistness or driness of the air.

§. 1106. It has been inquired, whether the air can be intirely deprived of it's elasticity, or only in part, so as to be reduced as it were to a languor. *Roberval* ^c affirms, that the elasticity has continued intire for the space of 16 years. It has also appeared to me by a most accurate experiment, that in compressed air the elasticity

^a Phys. Mechan. Exper. p. 170. Tentam. Florent, p. 39. p. 1.

^b Bernoul. Hydrodyn. Sect. 16.

^c Du Hamel Hist. Acad. Reg. L. 4. S. 6. C. 1.

has remained unhurt for 5 years. *Hauksbee* was of opinion from some experiments, that by compression the air might be reduced to a languid state. For air remained for some time condensed in a vessel, and then was freely committed to itself, so that it might go out as much as it could; then the vessel was again shut up, and after some time was again opened as hot as before, and again the air went out. This seems to be reduced to some degree of languor, or otherwise it would have gone out of the vessel the first time. But this observation is not without it's difficulties. However *Dr. Hales* has proved, that it may be deprived of it's elasticity by the burning of brimstone.

§. 1107. Air freely let alone to itself, and delivered from any cause that compresses it, always expands itself in form of a sphere, within the interstices of fluids. This may be seen when fluids are put under a receiver, and the air exhausted from that and them by means of an air-pump.

§. 1108. How far can the air expand itself by means of it's elasticity, when it is committed freely to itself, and is no longer compressed by any external force? It will be very difficult to give a satisfactory answer to this question, because the atmosphere is composed of very different elastick fluids, the elasticity of which varies very much. If it were therefore inquired, how much is virgin air expanded, and how much every other elastick fluid? First, these fluids must be taken pure and unmixed, which is a very difficult thing to do. Then there is another difficulty, which is, how shall we dispose such particles *in vacuo*, that they shall no longer act upon one another, but may be committed freely to themselves? This is a problem

problem that has not yet been solved. From some gross experiments, made upon a pretty large mass of air, it seems to be collected, that such air as is upon the earth's surface has been so rarified and swelled, that it possessed a space 4000 times greater than before. But giving attention to an elastick fluid, which is mixed with water, I often observed, that a single particle of such a fluid in warm water expanded itself into a volume 46656000000 times greater than it appeared to be before.

§. 1109. Air is very necessary to most animals that respire after the manner of mankind. For they are sustained by breathing it. So that animals included in a receiver, out of which the air is exhausted, cannot breath any longer, nor will their lungs be expanded; which left to themselves are contracted by their own contractile force, compress the blood-vessels, and hinder the blood from passing through the lungs, and out of the right *ventricle* of the heart into the left: So that the circulation stopping, the animal must die. The larger birds, as also land-animals, die very soon. Fish protract their lives something longer, yet die at last. Some insects continue to live *in vacuo*, and others die; all of them swell, because the air that is lodged in the blood and humours expands itself in the vessels, when the outward pressure of the atmosphere is taken off, and so causes a swelling through the whole body.

§. 1110. Animals live a long time, and with pleasure enough, in air that is condensed, especially if they have supplies of fresh air, and some of the stale be let out of the receiver. Hence divers can live very well within a large bell that is sunk under water, in air that is compressed by

300 feet of water, and 9 times denser than that upon the earth's surface; but they must be sometimes refreshed with new air, and some of the stale air must be expelled out of the bell; as is confirmed by daily experience ^a. Otherwise if many animals are shut up in the same air, without being sometimes renewed, they soon die; and so much the sooner the smaller the vessel is, in which they are contained. Is this because of the expirations from their lungs, and the transpirations from the other parts of their bodies, which are injurious to life and unfit for respiration? Or because animals consume the air in respiration, or reduce it from an elastick to a fixed state? Or rather is there something in air that drawn in with the breath nourishes and sustains living creatures, which is necessary for the preservation of life, and being continually secreted from the air is mingled with the blood in the lungs, which being consumed by the animal in the vessel, puts a period to it's life? There are Philosophers that espouse all these opinions, but perhaps he that takes them all in will approach nearest to the truth.

§. 1111. As air is necessary to the life of animals, so it is the chief cause of the vegetation of plants; for no seed that is committed to the earth *in vacuo*, watered, and nourished, will sprout and grow as in the open air ^b. Nay, every little plant, even the least moss, or weeds growing in water, immediately die in a place where there is no air, or where it is always stagnant ^c.

§. 1112. There are watery vapours floating in the air, sometimes more, sometimes less. But

^a Phil. Transf. N. 414. Clare's Motion of Fluids.

^b Philos. Transf. N. 23.

^c Boerhaave, Chem. V. I. p. 428.

water penetrating into the pores of vegetables and animals, moves the parts, relaxes them, and makes them swell. Therefore air abounding with vapours, and insinuating itself with them into the pores of some bodies, makes such bodies undergo the same changes, by this vapour, as by water itself. Philosophers have endeavoured to measure the quantity of vapours, with which the air at different times has been impregnated. The instruments contrived for this purpose have been called *hygrometers*, *hygrostatbicks*, *hygroscopes*, or *notiometers*; the invention of which is ascribed to *Maignan*. They are made of a very different figure, either of wood, strings, guts of animals, parchment, sponges, leather, cotton, ears of corn, oil of vitriol, &c. The *Florentines*^a have delivered the best method; and *Leupold* has collected many others^b. But we should confide in none of them, for all are subject to great defects; and both the old and new differ much in their easiness of motion.

§. 1113. Nor will it be either useless or unpleasant to consider the whole atmosphere, of which we have hitherto taken a view only of some parts. The atmosphere surrounds the whole terraqueous globe on all sides; which if it were at rest, nor moved with a diurnal motion about it's axis, by the laws of gravitation it would be of a spherical figure; because a fluid cannot be at rest, unless the whole surface were equally distant from the center.

§. 1114. But the earth revolves about it's axis with a diurnal motion, and the atmosphere together along with it. Therefore it's parts will re-

^a Tentam. Flor. p. 14, et seq.

^b Theatr. Stat. Univ. p. 1. c. 7.

cede from the axis with different centrifugal forces, so much the greater as the parts are more distant from the axis, by §. 411. And they will also withdraw by a direction perpendicular to it.

§. 1115. Therefore the figure of the atmosphere will become that of a spheroid; for it's parts in the equator, and places near it on each side, are much farther from the axis than in places nearer the poles; and at the poles, or above them, the centrifugal force will be least. Therefore the greater axis of the atmosphere will pass through the equator, and the lesser through the poles.

§. 1116. Because in a plain passing through the equator the centrifugal force is directly opposite to gravity, the air incumbent over the equator and neighbouring places will suffer the greatest loss of gravity; and so much the less the nearer it is to the polar regions. For which reason under the poles the centrifugal force receives no diminution of gravity, whereas it acts against it in a perpendicular direction under the equator. Wherefore the weight of the atmosphere over the equator must be the least, and near the poles the greatest of all; as the observations made with the baroscope sufficiently evince.

§. 1117. Also the air over the equator must be much rarer, as weighing less, and less compressing the inferior air on which it incumbs, than in places having a greater latitude, in which it is closer or denser.

§. 1118. Therefore though the atmosphere may every where receive and imbibe the same exhalations of earthy bodies, yet near the earth's superficies the air in different regions will be of a very different density and rarity. This difference is increased by mountains, vales, exhalations of different sorts, and vapours. Men find this by experience,

experience, when in some countries they observe the air to be more agreeable to the state and constitution of their bodies than in others ^a.

§. 1119. In the upper part of the atmosphere the air is left freely to itself, and therefore expands itself as much as it can. The loftier the air is, and the farther it retires from the impurities of the earth, so much the sincerer and purer it must be; the lower and nearer part to the earth, being compressed by the weight of the upper part, will be more compact and reduced into a less volume. Therefore if we imagine a right line extended from the earth's surface to the superficies of the highest part of the atmosphere; in this there will be airy particles of various magnitudes, and so much the greater as they are nearer to the outmost limits.

§. 1120. Because in the baroscope the mercury is pressed by the weight of the atmosphere, so that in this climate upon the earth's surface the mercury ascends to the height of 29 inches; if any one with a baroscope should ascend to the top of a high tower or mountain, so great a quantity of air would not incumb upon the mercury there as below. The mercury here being less pressed, would be suspended at a less altitude in the tube. And experiments made in many countries have verified this. I have tried it myself in the highest tower of *Utrecht*, and have found the mercury to descend in the tube $\frac{1}{2}$ of an inch, whenever I ascended $82\frac{1}{3}$ feet. *Feuillée* on the shore of *Teneriff* observed the height of the mercury to be 27 inches $9\frac{5}{8}$ lines. Then he went up into the highest mountain, of 2193 fathoms, at the top of which the mercury was only 17 inches 5 lines high. Yet this will not always

^a Lucret. L. VI, V. 1101.

obtain

obtain in a like proportion in the same country, or even in different countries. Because the atmosphere is not always equally heavy, nor equally pure, nor impregnated with exhalations that are equally weighty: as also not equally hot or cold, nor equally elastick. Hence it happens, that he that examines another's observations, does not always find them to agree, though made in the same mountain ^a.

§. 1121. If experiments are made with the baroscope at different heights of some very high mountain, the mercury does not subside in a constant proportion, as would follow from the law of elasticity; but it always descends less the higher we ascend. This is shewed by many observations made by *Cassini*, *Clapjes* ^b, and *Scheuchzer* ^c: Yet the expansions of the air are far from being in an inverse ratio of the pressing weights, since in the upper air the expansions were in a greater ratio than the inverse duplicate ratio of the weights. This depends, first, on the various centrifugal forces, by which at different heights the parts of the air are impelled upwards. Secondly, on the different gravity of the air at different distances from the center of the earth; according to §. 228. And thirdly, the purity of the air, and the elasticity thence arising, are variable at different distances.

§. 1122. Because therefore the law of elasticity in the upper air is yet unknown, from thence the true altitude of the atmosphere cannot be derived. Also the method of determining it from the twilights must be very uncertain, since we cannot exactly assign their beginning and end.

^a Tentam. Florent. p. 51. &c.

^b L'Hist. de l'Acad. Royal. An. 1705. 1733.

^c Phil. Transf. N. 405.

§. 1123. If we cast our eyes upwards, we shall see the sky blue; because the celestial spaces above the atmosphere are void, and therefore appear black: But the air reflects the light of the sun, not by separating it into little rays. This light is white, and therefore when we view the heaven, and the blackness mixed with white light, we perceive a blue colour. Thus painters of white and black paint mixed together make a blue colour; for the air does not separate a blue colour from light; for then all objects, receiving the light reflected by the air, would appear blue.

§. 1124. As often as terrestrial bodies are in fermentation, effervescency, putrefaction, combustion, or being fluid boil upon fire, they emit exhalations out of themselves, which are fluid, rare, thin, hardly conspicuous, elastick, sonorous, like to air, yet differing from it in their properties, as we have seen §. 1060. These and other elastick fluids are found in the air; which also should be examined had we time for it. Some things relating to these may be seen in the discourses of those most excellent Philosophers, *Boyle, Mariotte, Cotes, Reaumur, s'Gravesand, Hales.*

C H A P. XXXVII.

Of S O U N D.

§. 1125. **S**OUND denotes some condition in the sounding bodies; and secondly, a certain affection communicated to the air by these sounding bodies; and thirdly, the idea or perception formed by the mind, after the organ of hearing has been affected by the sounding air. I shall treat of these three things in this order, but very briefly.

§. 1126.

§. 1126. We may observe sound to be excited, as often as a solid or fluid body moves swiftly through the air: as when a slender twig vibrates swiftly backwards and forwards. Secondly, when the air strikes very rapidly against solid bodies at rest; as when the wind blows against trees, cables, pipes. Or thirdly, when two solid bodies, placed in the air, dash against one another. But the air alone never sounds of itself, nor solid bodies *in vacuo*; but it is necessary that there may be air, and bodies moving in it.

§. 1127. We must therefore enquire, what motion is required in the solid body, so that the air may be affected in such a manner as to produce sound. Let there be set before our eyes the elastick strait string A B, stretched at each end A and B. By some cause or other E let this be bent into the situation A E B, and then let loose on a sudden it will restore itself by it's elasticity, and pass into an opposite situation A C B. Now while it vibrates in this manner, those parts which were accumulated on one another, as in F G, will partly recede from one another, when the string is bent into the situation H I K, and are partly compressed to one another, because the thickness of the string decreases. Therefore the composing parts sometimes recede from one another, and sometimes accede, as the string by going and returning passes from one inflexion to another. The sound of the body does not consist in these kinds of motion. But if the string A B is struck by some hard body, so that it is not only bent into the situation A E B, but the parts so struck are also agitated by another tremulous motion; then during this tremor of the parts a sound is excited.

Tab. 23.
Fig. 2.

Tab. 23.
Fig. 3, 4.

Tab. 23.
Fig. 2.

This appears from the following experiments.

O 2

First,

First, let A B be the string of a harpsichord, which is struck with a crow-quill, and therefore oscillates and sounds. When the key falls which is covered with cloth, the sound ceases, and the string continues still to vibrate. Let a hard body be held near it, against which it may impinge, and it will sound again, but the oscillations are hindered by this body and not encreased; yet a sound is excited, because a new tremor is induced to the parts that are touched.

Secondly, let the string A B, which is stretched upon a violin, be struck with a bow that is anointed with tallow or oil; the string will vibrate, but no sound will succeed: but let the bow be made rough with resin, and the string struck with it then will sound; for the parts now will not only oscillate, but also tremble with a different motion.

Thirdly, a different sound is heard according as a string stretched upon a violin is struck with a different direction, either perpendicular to it's length, or oblique to it; which does not depend on the vibrations; for the string vibrates in the same manner, but the sound differs because of a different tremor of the parts.

Fourthly, if a long string is struck to produce a sound, not one sound only, but several are heard, and as it were an intire concert, as some skilful musicians testify. There is indeed but one species of oscillation, but several kinds of tremors, as some of the parts tremble more easily and faster, others more slowly.

Fifthly, this obtains not only in strings, but in all sounding bodies whatever. For let a bell be struck, and it will give a sound. Stay a little till the sound is heard no longer, but the oscillations of the bell do not yet cease; then let some hard

I

body

body be held close to the bell, upon which it may incur with it's vibrations, and a sound will be produced again.

Sixthly, if snow falls upon a bell, it will hardly sound if struck; not because there are no vibrations, but the subsultory motion of the parts ceases, that was produced by the stroke of the hammer.

Seventhly, if the hook A C B be first drawn together, and then let loose, so that it may be agitated by it's elasticity and made to tremble, it will not sound; but let the part C A incur outwardly upon any hard body, a sound will presently be heard, although the oscillations will be diminished. Tab. 23.
Fig. 5.

Eighthly, if a string has but a small tension, and be violently struck, it will yield but little or no sound, although it's oscillations will be large; but if it be very much distended, though struck but lightly, it will give a loud sound.

He that would see this opinion supported with more arguments, may consult *Perault*^a, *Carrè*^b, and *de la Hire*^c.

§. 1128. Therefore because sound consists in a tremulous or subsultory motion of the parts in the sounding body, and the various degrees of tremor may be greater or lesser; also the intenseness of sound will depend both on the magnitude of the tremor communicated to the parts, and likewise on the multitude of the trembling parts: Therefore to the exciting of an intense sound a cause violently striking the body is required. Also it must be hard; for if a bell be struck with a hammer of soft wood, it will hardly sound; but

^a *Essay de Physique.*

^b *L'Hist. de l'Acad. Roy. An. 1709.*

^c *L'Hist. de l'Acad. Roy. An. 1716.*

if with one of metal, or of very hard iron, although no heavier than the former, it will sound much more intensely. If a musical string be struck with a crow-quill, a pleasing and intense sound will arise: but if it be a flexible goose-quill, or from any other bird, when the string is struck it will hardly sound.

§. 1129. Because all elastick bodies are fittest for receiving and continuing tremors, they will also be most sonorous, as is found by experience. Hence strings are made of brass and iron wires, also of the intestines of animals; and musical instruments of very elastick wood, which when a sound is once produced will continue it for some time; but the parts of soft woods hardly tremble at all, and such bodies being struck give no sound, at least of no continuance; as when we strike lead, or a fluid is poured out of one vessel to a fluid in another.

§. 1130. If two stretched strings are struck, and give a sound, and one finishes it's vibrations later, the other sooner; the sound excited by each, and compared together, is called a *tone*; that will be the *graver* which is excited by the slower vibrations, and that the *acuter*, made by the quicker. Therefore all sounds are referred to *grave and acute tones*: but the terms where the grave cease, and the acute begin, are at discretion: These are sometimes fixed by musicians at the middle C of the harpsichord.

§. 1131. Therefore the celerities of the tremors seem to have some correspondence with the celerities of oscillation, at least on many occasions; for this is not universally true, as we may infer from tones made by strings, which are struck in oblique direction, or a transverse one; as also when it is squeezed by the finger at the obstacle,
either

either more lightly or more strongly, which produces very different tones with the same vibrations.

§. 1132. A stretched string, struck with not too great a force, produces the same tone from the beginning to the end.

For it has been observed, that the inflexions ACB , ADB , AEB , of the string AFB , by weights C , D , E , hung at the middle, are as these weights. Now whereas the action of elasticity is as the inflecting weight, it will be as the inflexion, or the distance from the point F : wherefore the action of elasticity may be compared with a heavy body moving in a cycloid PQR , the force of which is always as the distance from the lowest point Q : therefore this body will finish its oscillations great or small in equal times. And thence the elastick string will perform its oscillations ACB , ADB , AEB in equal times, and will give the same tone. Tab. 23.
Fig. 6.

§. 1133. Mr. *Sauveur*^a has computed the space passed over by a string in a certain time, when it is agitated by the greatest vibrations, and then by the least, still producing the same tone; and has observed, that the space in the first case, within a second of time, is 72 times greater than in the other. From hence it follows, that the intenseness of the sound, without changing the tone, may be 72 times greater than before. Tab. 23.
Fig. 7.

§. 1134. But as in greater inflexions the elasticity reacts in a greater proportion than according to the inflexions; a string very much struck and bent, will perform its vibrations quicker, and therefore will produce an acuter tone. Nay, it may happen, that it may squeak. Hence it is,

^a L'Hist. de l'Acad. Roy. An. 1700.

that a pipe, when strongly blown into, gives a much higher tone than when moderately blown.

This may be shewn by a comparison with two pendulums of equal length, but agitated with different forces of gravity; for the times of their oscillations will be in the inverse subduplicate ratio of their gravities, by §. 392.

Tab. 23.
Fig. 8.

§. 1135. It has been observed, that a string AB 96 feet long, and stretched by a certain weight, has vibrated once within one second. A bridge being put in the middle C, one half of the string finished two vibrations in the same time. Another bridge being fixed at D, the middle of CB, the part BD vibrated four times. A bridge being put at the middle of this E, the part BE vibrated 8 times in the same space of time.

So that the number of returns was always reciprocally as the length of the string.

§. 1136. We observe besides, that the stretched string AB gives a certain tone, and the string CB gives a tone higher by an octave. DB also is an octave, and EB is the octave of this; wherefore the acuteness of tones are reciprocally as the lengths of the strings.

§. 1137. Therefore tones are excited by strings, that complete determinate vibrations in a certain time. As often as the vibrations, completed in the same time, are to one another as the following numbers, the tones by musicians have been distinguished by names.

- 1 to 1 is an unison.
- 2 to 1 is an octave.
- 3 to 2 is a fifth.
- 4 to 3 is a fourth.
- 5 to 4 is a third major.
- 6 to 5 is a third minor.
- 5 to 3 is a sixth major.
- 8 to 5 is a sixth minor.
- 9 to 5 is a seventh minor.
- 15 to 1 is a seventh major.

Seven tones constitute an octave; for the eighth tone will be the first of the following octave.

A good ear can distinguish 43 different tones in an octave^a: between every one of which other intermediate tones may be inserted, but such as the human ear cannot distinguish.

§. 1138. There may be many octaves either ascending or descending. *Sauveur* imagines, that every sound, which can be heard distinctly and with pleasure by man, is comprehended in ten octaves, Mr. *Euler* says eight^b; therefore the most acute tone will make 1024 vibrations, in the same time that the most grave shall complete 1. For in every higher octave there is half the time of the foregoing. But the number $\frac{1}{2}$ raised to the tenth power is $\frac{1}{1024}$.

§. 1139. The number of vibrations performed by stretched strings in a given time, is as the square-root of the weights that stretch them, divided both by the weight of the string, and also by it's length. Therefore if two strings of the same weight and thickness are stretched by different weights, the number of vibrations in a given

^a L'Hist. de l'Acad. Roy. An. 1700.

^b Tentam. Musicæ, c. 1.

time will be as the square-roots of the weights. And therefore if the weights are as 1 and 4, the strings will give tones that are octaves to each other.

§. 1140. If two strings of the same thickness are different in length, and are stretched by weights, which are as the squares of the lengths, they will have the same number of oscillations in the same time, and therefore will be unisons.

§. 1141. If two strings of the same length differ in thickness, being stretched in the ratio of their thickness they will be unisons.

§. 1142. Therefore two strings of different length and thickness, stretched in a ratio compounded of the ratio of the thickness and the duplicate ratio of the length will be unisons.

§. 1143. From this doctrine it appears, why in musical instruments strings of different thickness and sometimes of different lengths are made use of. Why when the shorter strings are struck they give very acute tones? And why from the lowest note of the bass the same string may be so disposed, that it may be most acute? How the number of oscillations may be known for every tone, from the first that is audible and very deep, to that which is most acute, and which almost squalls to an human ear: since the vibrations of that in a second are as $12\frac{1}{2}$, but of this 12800 : for $12\frac{1}{2} \times 1024 = 12800$.

§. 1144. What we have delivered concerning the vibration of strings obtains in all sonorous bodies, which being struck are excited into like vibrations and tremors of the parts, as appears from bells, drinking-glasses, &c. These when struck change their round figure into an oval one, by succession, as we prove to the eye. Now that the same thing happens to these, as to their tones and

and number of their vibrations, appears by *Galileus's* experiment*. For when he pressed hard with his finger the brim of a drinking-glass full of water, a sound was raised, and waves in the water. Then straining the glass more forcibly with his finger, that the tone might be an octave higher, lesser waves were produced, which most accurately divided every one of the former waves into two equal parts.

§. 1145. Let us now briefly examine what sound is in the air, the theory of which is most subtile, and which however the great *Newton* seems entirely to have exhausted. I shall only touch upon some of the simpler fundamentals, which may be apprehended by novices. Because waves raised in the air produce sound, I shall shew in short what these waves are, that are thus excited in the air.

§. 1146. Let us therefore conceive in our minds airy particles a, b, c, d, e, f, placed at equal distances from one another. At a let there be an elastick body, which is hard and tremulous, whose parts strike against the air, and move it in the direction a f. Or let a good quantity of air, which is vehemently compressed, be let loose on a sudden, and in a like manner strike against the other air with the direction a f. It's particles a, b, c, being swiftly moved, will strike against the parts before them, which will resist them. But by moving these they will be coacervated and condensed, till the elasticity of the condensed air by it's resistance takes away the motion of the incurring parts; therefore in some intermediate place e, between d and f, the density of the air is greatest, less in d, c, b, and least in a.

Tab. 23.
Fig. 1, 9.

* *Mechanica Dialog. I. p. 90.*

Therefore

Therefore the denser and more elastick air in *e*, will drive back the particles which had departed out of their places, so that *a* will return into it's former place, as likewise the other intermediate particles between *d* and *a*.

§. 1147. And thus the first aerial wave is formed. Now because the particles *e*, *f*, expand themselves every way by their elasticity, they will also be urged by a direction towards *m*. And assuming the distance *f m* equal to *a f*, the greatest density of the air will again be generated between *k* and *m*, and the least in the middle between *e* and *k*; because the elastick parts *e* and *f* by restoring themselves, by their motion received will be expanded to a greater rarity. Wherefore by a greater action of elasticity between *k* and *m*, the particles will be again drove back in the directions *l e*, *l r*, till the intermediate ones have recovered their former place and density. Thus another wave is formed, and in the same manner the succeeding waves will be formed.

§. 1148. These waves are not like those which are formed concentrically in the plain surface of standing water; but those in air are formed as it were in the superficies of a sphere. Because the condensed air expands itself all manner of ways with equal force; and these waves are not made in an extreme superficies, but in the middle of the air. These waves produce sound, which is propagated after the following manner.

§. 1149. Every sound is propagated in a spherical expansion, in whose center is the sonorous body. Let a bell be hung in the middle of an ample place; this being struck will be heard on all sides wherever the ear is placed. Hence the intenseness of the sound decreases in the reciprocal duplicate ratio of the distances from the sounding body.

§. 1150.

§. 1150. Every sound also has it's limits, beyond which it is no longer heard.

For if any one that speaks with a loud voice may be heard at the distance of 100 perches, he cannot be heard at all at the distance of 1000. But can the limits be assigned, beyond which a sound cannot be heard? Not at all. For these depend on the magnitude of a sound, which cannot be determined. How far indeed a sound has been carried, is known in a manner from some observations. At *Florence*, at the request of *Newton*, some guns have been discharged, the sound of which was heard at *Liburn*, and at the old Tower upon *Mons Rotundus*, which is 5 miles farther off. The distance of *Florence* and *Liburn* is 50 *Italian* miles. The way between them is mountainous, and the wind did but little favour the passage of the sound. And guns discharged at *Liburn* are heard as far as *Porto Ferrajo*, which is 66 miles distant from thence. When the *French* besieged *Genoa*, the sound of the guns was heard at *Liburn*, which is at the distance of 90 *Italian* miles ^a. Yet nothing certain can be determined as to the limits of sounds, even though the magnitude of a sound might be known; because it's propagation depends on the wind, on the purity of the air, on the intermixed exhalations, the elasticity, density, heat of the air, and on the intervals between it's several particles.

§. 1151. Sound is propagated pretty slowly ^b, and not always with the same velocity, whether it be in the same or in different countries, even though the wind should not blow at all. *Gassendus* seems to have been one of the first, that gave

^a Philof. Transf. N. 113.

^b Lucret. l. 6. v. 166.

attention to the space described by sound within a given time. He found that in a second sound travelled 1473 feet. But the *Florentine* Philosophers, by the discharging of guns, from which they were distant a known space, determined the velocity of sound more accurately. For whereas the flame is seen nearly at the same time both by near and remote spectators, the distance of time between seeing the flame and hearing the sound by the observer, at a given distance from the gun, will give the velocity of the sound. According to the *Florentines* sound will describe 1185 feet in a second ^a. Some of the ablest Philosophers in *France*, Mr. *Cassini*, *Huygens*, *Picart*, *Romer*, applying themselves to the same enquiry, assigned a space of 1172 *Paris* feet to the passage of sound in a second ^b. In *England* the same thing was tried by *Flamsteed* and *Halley*, who made it 1142 *London* feet, that is 1070 *Paris* feet. And this mensuration was espoused by the great *Newton*. Others found another degree of celerity: nor is it to be doubted, but that in *Italy*, *France*, and *England*, the observations were made with the greatest diligence. And hence I concluded, that sound is not equally swift in all regions of the earth. Yet Mr. *Durham* has made this decision doubtful, saying, that in all weathers, whether the sky be clear and serene, or cloudy and turbid, whether it snows or rains, thunders or lightens, whether hot or cold, day or night, winter or summer, whether the mercury in the barometer rises or falls, in all changes of the atmosphere, wind only excepted, that the velocity of sound is neither greater or less, but only the sound will be more or less loud.

^a Tentam. Florent. p. 113.

^b Hamel. Hist. Acad. Reg. I, 2. sect. 3. c. 2.

§. 1152. By knowing the velocity of a sound in it's passing through a determinate space, the number of pulses or waves, and their distance in the air, may be known by help of the rules delivered by the great *Newton*^a. Let the number of vibrations be found, by which the sounding body is agitated in a given time. By this number let the space be divided, which a pulse can pass through in the same time, and the part found will be the latitude of one pulse. Mr. *Sauveur* has found, that an open pipe, of about the length of 5 feet, will give a sound of the same tone with the sound of a string, which vibrates 100 times in a second; wherefore about 100 waves will be raised in the space of 1070 *Paris* feet. Hence every wave will be distant from the next $10\frac{7}{10}$ feet. Now because a very acute musical tone will be given by a string that makes 6400 returns in a second, it's waves will be from one another only $2\frac{1}{80}$ inches.

§. 1153. This law of sounds may be of great use to mariners, because they may nearly know, by the firing of guns, and by their flash being seen and report heard, how far ships are distant from them. It may be of use to soldiers in besieging a town, that they may know how far they are from the town when they begin to make their mines. It is convenient also for Geographers for measuring the distances of places, as often as inaccessible rocks lye between the places. Also it may something advance our security, to know the distance of thunder from the place in which we are.

§. 1154. A great and a small sound is equally swift in passing through the same space, though a

^a *Philos. Natur. l. 2. §. 50.*

great one may go further. This was found by the *Florentines*, by their experiments made with guns of different kinds. *Durham* has confirmed the same, by observing, that a knock with a hammer, and the report of a gun, passed the space of a mile in the same time.

§. 1155. The same sound is observed to be always equally swift in it's passage, and therefore the celerity of the aerial waves is equable.

The *Florentines* were the first that observed this; for when at the distance of 3000 cubits they heard several cannons to be discharged, and counted 10 half-seconds: at a distance half as much they observed the sound to arrive in half the time. *Derham* afterwards confirmed the same by his observations, that is, when the motion of the sound is horizontal^a. But does sound ascend and descend with equal celerity? Perhaps sometimes it ascends into a mountain with more speed than it descends, as *Derham* has inferred.

§. 1156. A fair wind accelerates sound, and so much the more the stronger it blows; but a contrary wind retards it.

Gassendus concluded from his experiments, that the wind neither accelerated nor retarded sound. The *Florentines* confirmed the same by their experiments. But Mr. *Derham* having frequent opportunity of observing the velocity of sound, came to another conclusion. He found that when the wind was fair, sounds passed between *Blackbeath* and *Upminster* in the time of 111 half seconds. But when the wind was contrary, the sound did not complete the same space but in 122 half seconds.

^a Phil. Trans. N. 313.

§. 1157. A fair wind carries sound to a greater distance than it would be carried with a contrary wind.

§. 1158. If guns are discharged with a horizontal direction towards the place of observation, or with a contrary direction, or at any angle whatever to the horizon; the sound in it's passage is always equally swift, and moves with a like velocity over uneven and crooked places, as over smooth ones.

§. 1159. A greater sound stifles a smaller, so that it is either not heard at all, or indistinctly.

For if you are near a large bell while it sounds, one that is near you cannot hear you speak. Nor can you be heard any better if you are placed among drums, and the discharging of great guns.

§. 1160. Because sound in the air is a kind of wave; it may be reflected by a body on which it impinges, and so return to the place from which it departed.

The same sound reflected to the place of it's original, and there perceived distinct from the first, is called an *image* or *echo*.

§. 1161. The interval will be the shorter between this and the primary sound, the nearer the obstacle is to the cause of the sound. If the distance of the obstacle from the cause be 535 feet, there will be the distance of a second between the primary and reflected sounds. So that all the words pronounced by any one within this time, if he then ceases to speak, may be heard again, as if pronounced by the echo. The farther the obstacle is distant from the cause, the more time before the return of the image; wherefore such an echo may consist of many syllables, though if the obstacle be near the sounding cause, it may be only of one syllable.

§. 1162. Because the mind does not distinguish sounds, which arrive at the ear with too swift a succession, but some interval is required that they may be heard distinctly; therefore though the place may be such as would return the sound to the speaker, yet because of the nearness of the obstacle no echo is heard. Skilful musicians generally exhibit 9 or 10 distinct tones, on the strings of a violin, within a second of time, when they play very quick, or what they call *prestissimo*; and therefore the ear of an exercised musician can only distinguish the image, when the reflected sound follows the direct sound with the same swiftness as a tone follows a tone in a tune. Now that this may be perceived, the obstacle ought to be distant $53\frac{1}{2}$ feet from the sounding cause; for if it is only 50 *Paris* feet, I doubt whether the best ear could distinguish the principal sound from the secondary one, but he would only hear a jarring. And a less exercised ear would require a greater distance of the obstacle, to hear and distinguish the echo from the primary sound.

§. 1163. If obstacles are at various distances from the speaker, of which the nearest are low, the remote ones higher; or if there shall be only two very high obstacles, which can return the sound to the same place, different repetitions of the echo will be heard, of which one will follow another; because the voice is generally heard more faintly, the farther it comes, the first echo will be the strongest which proceeds from the nearest place, the others weaker. So that if the word *ah!* be pronounced, it will represent the groans of a dying person. Also very high parallel walls will return repeated images, as were those of the town of *Simonetta*, described by *Kircher*, *Schottus*, and

and *Misson*, in one of which was a window, through which he that spoke heard his words 40 times repeated. Now because the motion of sound is equable, there will be equal times between the several repetitions; as *De Lagny* and *Derham* have observed.

§. 1164. Whatever can reflect back sound to the place from whence it came, may be the cause of an echo; therefore walls, old inclosures of cities, thick woods, houses, and rocks over a river, fields rough with turfs or shrubs, hollow and uneven stones, as also clouds, may reflect sound. Hence thunder-claps and the repeated murmurs of thunder. If a gun be discharged in clear weather, the sound will be heard only for a moment. But let thick clouds hang in the sky, and sounds will be produced that will continue some time.

§. 1165. Sound may also be preserved, by hindering it from expanding itself spherically. This may be done, if it be propagated in tubes or long passages, by the sides of which it is reflected; whence the sound remains undisturbed till it passes from one extremity of the canal to the other. Hence, as *Kircher* observes, a sound is carried perfect in the *Roman* aquæducts, which are 500 or 600 feet long; at the orifice of which if a person speaks, he may be heard and understood at the other extremity. By means of such canals, even though they are bent, a sound may be directed to any place. Also a sound, like light, may be collected into a small place, which will be as it were it's focus; as is proved by some chambers, the roof of which consists of an elliptick arch, in one of the focus's of which if any one whispers, he may be plainly heard in the focus of the other. Also tubes are made, which

Tab. 23.
Fig. 10,
15.

from a wide mouth A finish in a narrow pipe B, to be put into the auditory passage. The sound entering the wide aperture, and reflected a number of times by the sides of the tube, is as it were condensed, that it may enter the ear from a narrow part, and so may strike the *membrana tympani* most strongly. The same thing is observed when we apply our ear to the narrow orifice of a speaking trumpet, and direct the wider part towards the sonorous cause. By this method we assist those that are hard of hearing, as old men are assisted by spectacles. A sound may also be diminished and as it were suffocated, when it falls upon bodies of a loose texture, and less elastick, of an uneven surface, by making it not fit for hearing. Hence the voice of a pleader is much diminished in a chamber, whose walls are adorned with loose tapestry; or when in a popular assembly the sound is continually intercepted and suffocated, because of the frequent breaks between each person, and the looseness of their clothes.

§. 1166. Sound is increased, and carried to a much greater distance, by means of speaking trumpets. It is also increased by the elasticity of the tube, which being moved by the sounding air continues to tremble for some time, whence the same sound is as it were repeated; and thus the same thing is done, as if the same voice was uttered by many at the same time. Now whereas there is some notable space of time between the first sound, and the ultimate tremors of the same continued, the ear can distinguish the first sounds from the last. Hence a clangor arises, which causes the sound to become less distinct. Wherefore that the voice uttered through the tube may be distinctly understood at a great distance,

distance, it is necessary that every word should be distinctly pronounced.

§. 1167. *Alexander* the Great is said to have had such a tube, with which he called together his whole army, however dispersed, and spoke to them as if present before him. *Kircher* gives us a figure of it ^a, and afterwards had one made like it. After him in the year 1654, P. *Salar* at *Paris* had a tube made $5\frac{1}{2}$ feet long for musical uses. But Sir *Samuel Morland* applied himself to the improvement of these tubes, and after the year 1671 they became very well known. He put learned men upon finding out, what was the best form that could be given to the tube. This problem was attempted by *Cassaigne* ^b, *Coniers*, and others, but was best solved by *Hafius* ^c. He constructed a tube AB, consisting of an elliptical body AC, with a parabolick one CB annexed. Tab. 23.
Fig. 11. For if the mouth of the speaker be placed in A the focus of the ellipsis, the phonick rays AE, AF, AG, AH, reflected by the sides E, F, G, H, will meet in C the other focus of the ellipsis, which must also be the focus of the parabola CB conjoined with the ellipsis; the phonick rays CK, CE, CM, CN, proceeding from this focus C, will be reflected back by the sides of the parabola K, L, M, N, according to KO, LP, MR, NS, parallel to the axis CB, and thus they may be extended a great way. The parabolical form alone may be sufficient for smaller tubes; but long ones may be constructed of various ellipses, conjoined with the parabola.

^a Ars magna. L. 2. P. 1. C. 7.

^b Journal des Scavans, An. 1672. p. 131.

^c Tract. de Tuba Stenterophonica.

§. 1168. Now that we have seen what sound is in the sonorous body, and what in the air ; many other things may be understood, which depend on the action of both.

Let two musical strings be unisons, either in the same, or in two different instruments near to one another. When one is struck, the other string will sound also, and it's tremor will be sensible by putting some very light body upon it. For as the air is excited into waves by the trembling string, these strike against the other string, which easily receives the like tremors, because it is ready to tremble with the same velocity.

§. 1169. If there be two strings stretched upon two instruments, or the same, and octaves to each other, that being struck which gives the acuter sound, the other will sound also ; and in the middle of it's length this will have a kind of node which will not move at all ; because the string that has the acuter sound is agitated by the air into waves vibrating as fast again as the other string can move ; yet it shakes it, and agitates by tremors of the same celerity : and therefore this in it's middle must have a point at rest ; for if it was as short again, it would be unison with the tone of the other. But there are observed to be several intermediate points at rest in strings, which when struck would sound various octaves ; for by this means they all become unisons.

§. 1170. From hence it may be understood, when some bodies are sounding, why our limbs and bones shudder ? Why the glasses of windows, drinking-glasses, houses themselves, and other bodies in them give a sound ? For all things that are strung to unisons, or the graver octaves, to the sounding body that is struck, must sound with it, as it happens to musical strings, by §. 1168, 1169. Secondly,

Secondly, why does all sound cease in Mr. Boyle's vacuum? Because though the bell may vibrate *in vacuo*, yet it cannot communicate its tremors either to the air, or to any other body: therefore there is nothing to move the external air, or shake the organ of hearing.

Thirdly, if the experiment is not tried very accurately, though all the air be exhausted out of the receiver, yet if the bell can communicate its tremors to the receiver, or any other solid body on which it stands, which may impart its tremors to the external air; then some sound will be heard if the bell be struck.

Fourthly, is not the sound diminished in thinner air, because of a less degree of elasticity in rarified air? Therefore in a denser air the intenseness of the sound must be increased. And a bell shut up in condensed air may be heard to a greater distance than when it sounds in a thinner air. If this be true, then the elasticity of the air being increased, and the same density continuing, as when air included in a receiver is heated at the fire, the intenseness of the sound must increase also. That it is so, some Philosophers have also observed.

Fifthly, when pipes are blown into, does the sound depend on the tremulous motion of the reed or tongue, as also of the air passing through the pipes, the waves of which are propagated quicker or slower according to the different lengths of the pipes, or the situation of the holes on the sides? Or does the sound of pipes depend on the tremors of the internal air only? Many things are still behind, which regard sound in the air, but which cannot be discussed in these institutions.

§. 1171. It is now necessary to consider briefly

P 4

what

what sound is in the mind, and how this is affected by the sense of hearing. But this cannot be done till in some measure we explain the structure of the ear, as we described the eye when we treated of vision. Men have two ears disposed in such a manner on each side of the head, that whatever sound approaches to the head must strike one or both.

Tab. 23.
Fig. 12.

§. 1172. The proper substance of the ear is cartilaginous, thin, elastick, that it may easily be excited into tremors by the waves in the air. It is covered with membranes, that sounds may not become jarring. The external superficies AB has certain eminences, and cavities, appointed and fitted for receiving, reflecting, and directing sound into the hollow of the ear, that it may not fly off and escape, before the sense is affected by it. Also it may be so extended, expanded, and flatned, by means of three internal muscles, and as many external, that it may be adapted to receive, and on some occasions drive away any tremors and sounds whatever, and that it may tremble in harmony with them.

§. 1173. At the bottom of the *concha*, under the cartilaginous *tragus* C, begins the auditory passage, which is of an elliptical figure, whose aperture is generally $5\frac{1}{3}$ lines of square inches, and of a magnitude in respect of the whole ear, as 1 to 50. So that the sound falling upon the ear, and entering the passage, may be 50 times more intense than if it had entered the passage without striking the ear. Here is the tube DE, having hard and as it were horny entrances, being partly bony and partly cartilaginous, 9 lines long, 4 deep, and 3 broad, of a cylindro-elliptical figure, ascending with a serpentine process DF, then descending as FE, and again ascending. It is terminated

minated by the membrane of the *tympanum* G, placed obliquely, forming an obtuse angle on the upper part, and an acute one below, that the sound might not strike it directly, but after various reflections in this tube, might fall very obliquely upon the membrane from the upper part downwards. By this structure it continues safely defended for a long time, nor is it easily burst by violent sounds.

§. 1174. The *membrana tympani* closely adheres on all sides to the margin of the bony passage, and is no where perforated. It is concave towards the external part of the ear, and convex towards the internal. The handle of the *mallet* h adheres to it extended almost as far as it's middle. Now the *mallet* is connected by a joint to the *anvil* k, this to a little *bone* i, and this to the *stirrup* n. Three muscles fixed to the *mallet* are the means by which the *membrana tympani* may be distended, relaxed, may become more convex or flatter; by which it is brought to pass, that it may tremble harmonically with the sound affecting it.

§. 1175. After the *membrana tympani* there follows a remarkable cavity, called the *tympanum*, or the cavity of the *tympanum*. It is of an irregular figure, like to an elliptical body, of the length and breadth of 4 lines. In this *tympanum* are placed the four little bones aforementioned. Into this also open the mouths of the *cellule mastoideæ*, also the *fenestra rotunda*, the *fenestra ovalis*, and *Eustachian* tube M. The air passes freely through this out of the cavity to the inward part of the mouth, and enters into the cavity out of the mouth, so that it may have the same elasticity with the external air. When the exterior sonorous air affects the *membrana tympani* G,

G, by the tremor of this the internal air of the *tympanum* will be excited into like waves.

§. 1176. The other internal part of the ear is the *labyrinth*, in which we first meet with the *vestibulum*, which is hollow, of an irregular figure, the length and breadth 2 lines, and one and an half deep, entering into the *os petrosum*. Into this open the five orifices of the three semicircular canals O, P, Q, and the orifice of the *cochlea* S, five orifices for the nerves above S, and the *fenestra ovalis*, which is shut up in a membrane, to which the *stapes* n adheres.

Tab. 23.
Fig. 13,
14.

There are three long semicircular canals, O, P, Q, having only five orifices, and an elliptical cavity within, opening into the *vestibulum* r; as also the *cochlea* S, which is a bony conoidal canal ST, involved about a cone, completing two revolutions and an half, which tend from the base to the acute apex T. The cavity of the *cochlea* is divided into two hollows, separated from each other by means of a very thin partition XZ, partly bony a, a, a, and partly membranaceous b, b, b. The fibres of this membrane run outwards from the axis of the *cochlea*, as rays of a circle from the center to the periphery, and therefore are of a very different length, reckoning them from the broader base to the vertex. So that this membrane is as it were a triangular scale, composed of many extended strings of different lengths.

The other cavity of the cochlea is terminated at the round aperture shut up by a thin membrane. This aperture ends in the cavity of the *tympanum*, and is opposite to the center of it's membrane.

§. 1177. The auditory nerve begins to be seen in the brain at *Willis's* annular protuberance, distinguished

stinguished into two parts, the *soft* one and the *hard* one, both which enter into a broad aperture in the *os petrosum*. Part of the *soft* enters the *vestibulum* r, through five apertures near S, and there forms a membrane, covering the internal superficies of the *vestibulum*, and of the semi-circular canals O, P, Q. Then they run within the duplicature of the triangular Scale X Z, (Fig. 14.) in the *cochlea*, in which they are expanded: And therefore this is properly the organ of hearing.

The cavities of this labyrinth are filled with a sufficient quantity of air, of the same elasticity of that in the hollow of the *tympanum*, which yet does not enter or go out at any particular aperture. It is only brought in with the humours, which are evaporated out of the vessels, that the nerves may continue limber. Which air is again absorbed with the same vapours, and so is perpetually renewed.

§. 1178. Wherefore the sense of hearing is performed after the following manner. The sound excited in the external air arrives at the ear AB, enters the *concha*, then the auditory passage DE, and communicates it's tremors to the membrane of the *tympanum* G. When this is set on trembling, the air in the hollow of the *tympanum* is also agitated into sonorous waves. These meet the membrane of the *foramen rotundum*, and put it into tremors. This affects the air contained in one of the cavities of the *cochlea*, which affects the nerves in the scale of the *cochlea* S, which motion carried to the brain by means of the nerve, produces the sensation of hearing in the mind. Perhaps indeed it does not hear very distinctly, yet it hears however in some measure. If the mind desires to perceive the tones very distinctly,

Tab. 23.
Fig. 12

stinctly, the membrane of the *tympanum* G is distended by means of the muscles of the *mallet*, that it may tremble in harmony ; also by means of the muscle of the *stapes* the membrane of the *fenestra ovalis* is distended, that this also may tremble harmonically with it's little bones, and with greater vehemence than it could be affected by the air of the *tympanum* alone. When this membrane trembles, the interior air in the labyrinth r will tremble also, which affects the nerves that are expanded over the internal superficies of the *semi-circular canals* O, P, Q, and at the same time those in the scale of the *cochlea* S. But any sound excited in this air, will affect some of the fibrils b, b, b, Fig. 14. which are harmonically distended by §. 1168, and 1169. And these will affect the nerves, which carry these motions to the mind by the *medium* of the brain, and are the occasion that the mind perceives very distinctly all sonorous tones.

C H A P. XXXVIII.

General matters concerning aerial Meteors.

§. 1179. **A**LL bodies that are above us between the heaven and the earth, which are suspended, float, move, are driven, set on fire, conjoined, separated, ascend, descend, and produce any phenomena whatever, we call *meteors*.

1180. Many and various exhalations continually expire out of the body of the earth, which mount aloft and are mingled with the air. These are the most subtile particles of almost all earthly bodies, whether solids or fluids, whether produced by nature or art. These are first, whatever constitutes

constitutes the odorous spirit of plants, flowers, or fruits, which is wont to exhale from them, and is volatile. Secondly, the waters of plants exhaling of their own accord, or drawn from them by the sun. Thirdly, burning spirits, which are composed of the fermented juices of plants, prepared by art in great plenty for the use of mankind, and are volatile; to which nature also produces the like, as often as the moisture escaping from succulent plants is committed to the warm air; or the plants themselves moistened with water are exposed to the same air. Hence the waters of some rivers ferment, and throw out burning spirits, as is well known of the *Thames*-water; and *Tylkowsky* has observed the same thing of the water of the river *Aluta*^a. Fourthly, the sun causes the oils of plants to become volatile, and disperses them through the air, as we are informed by drying them, by which we find they are so far discharged from their oils, that they cannot afford nutriment for fire. The dreadful stench that infects the laboratories of those that make soap depends only on their volatile oil. Fifthly, the salts of plants ascend also into the air, as the salt smoke of burnt plants shews us. As also by putrefaction, exsiccation, fermentation, they become volatile and escape. Sixthly, besides salts and oils, smoke carries with it also much volatile earth. The ashes of burning mountains, as of *Ætna* and *Vesuvius*, mount up into the air to the height of 100 miles^b. Also the winds of *Egypt*, *Ethiopia*, *Arabia*, *Guzarath*, and *Libya*, carry up the fine sands like waves, by which the army

^a Philosoph. Curios.

^b Philos. Transf. N. 21.

of *Cambyfes* was overwhelmed ^a. Seventhly, into the atmosphere are received all the subtilest parts that expire from the bodies of all animals, and which are known by the name of *Sanctorius's* perspirations. Eighthly, the sweat of animals. Ninthly, the very subtile oils of animals, produced by putrifying carcases. Tenthly, the volatile salts of animals. Eleventhly, of the fossil kind more fill the atmosphere than can be here mentioned; the chief are, the vapours of river waters and of the ocean. Twelfthly, sulphurs unburnt, which are thrown out plentifully from burning mountains, or are contained in the smoke of the pumice. Very suffocating acid spirits expire from these as they burn, such as from those places which are called *Averna*; as at *Cumæ*, in the citadel of *Athens*, and in *Syria* ^b. Hither are to be referred arsenic, auripigmentum, cobalt, sulphur of antimony, bismuth, zinc. Also those things which in other places proceed out of the superficies of the earth, and often take fire; as at *Gratianopolis*, and are described by *Blanchini* in the country of *Petræmala* ^c, such also as *Galatius* ^d has observed as he travelled to *Burigatia*; and other inflammables very elegantly described by *Ripa* ^e. There are also many springs, the waters of which are inflamed as soon as a candle is put to them, because of a thin sulphur, issuing out of the earth together with the water, and more volatile than itself ^f. Thirteenthly, oils of the earth,

^a Seneca. Q. N. l. 2. c. 30. Varenii Geograph. S. 6. c. 21.

^b Lucret. l. 6. v. 740.

^c L'Hist. de l'Acad. Roy. An. 1706.

^d Comment. Bonon. v. 1. p. 106.

^e Dissert. Meteorol.

^f Lucret. l. 6. v. 879.

and petreols. That is very volatile which is gathered from mount *Ciaro*^a. Fourteenthly, very different kinds of salts, all which are something volatile, and help to fill the atmosphere. Chiefly the matrix of nitre, vitriol, alum, sea-salt, &c. and the acid spirits of these bursting out of vulcanos, or produced up and down by subterraneous fires. Then the *acidum vagum* of fountains and mines; for this is used to corrode metals and other bodies in the air. Fifteenthly, as also the parts of all metals and semi-metals may be made volatile by common fire, whether alone, or by means of other bodies added to them. Sixteenthly, likewise innumerable other things which continually expire upwards out of the bowels of the earth; chiefly out of mines of metals, which make mens faces pale, or cause their deaths^b. *Lister* has took notice of four different sorts, that are found in mines of pumice^c, which extinguish the candles of the workmen, or suffocate them, or throw them into convulsions, or when set on fire disperse every thing with great violence. To which may be added the spirit in the *Grotta de Cani*, which rises only to a small height from the ground, or that which rises in the quarry of *Pyrmont*^d. As also that which is so deadly, and expires out of a well in the isle of *Wight*^e. A pestilential vapour proceeds out of a mountain of *Pbrygia* near *Hierapolis*^f. Whatever therefore can be done by the art of chemistry, by means of fermentation, putrefaction, solution, attrition,

^a L'Hist. de l'Acad. Roy. An. 1736.

^b Lucret. l. 6. v. 808.

^c Philos. Transf. N. 117.

^d Philos. Transf. N. 448.

^e Philos. Transf. N. 450.

^f Plin. l. 2. c. 93.

effervescency,

effervescency, or by fire, the same is also performed by nature, which uses the like operations, and ascends into the atmosphere, which thus becomes a most complete and perfect chemical laboratory, containing parts of all kinds of bodies, and innumerable compositions. Seventeenthly, besides all these many plants are dispersed and float in the air, such as mucagos, mosses, the most subtile and invisible seeds of plants and fungus's. Lastly, a great diversity of animalcula.

§. 1181. Sometimes vast quantities and large tracts of corpuscles of the same kind swim in the atmosphere, which only differ from their former condition, when being collected they composed a mass, that they are converted from solid to fluid, or from fluid to a rarer fluid; and their parts farther separated from one another, now being in the air, are in no wise contiguous or adhere together. So that they retain many properties which are not changed by their rarity, and can exert the same forces as before when they composed a fluid or a solid, or as soon as they shall be united again into one mass.

§. 1182. Such kind of tracts of uniform parts remaining in the atmosphere, when driven by the winds meet with other parts of a different kind, and are mingled with them. Then the same or like effects will arise, as we observe to be produced by the artificial mixture of the same bodies. But because we mortals have hitherto dissolved but very few bodies into parts, and mingled or compounded them together; but in the atmosphere there abide parts of almost all kinds of terrestrial bodies, which meet with one another, and are blended aloft; effects will arise from these that have not been yet observed, nor have we seen the like here below. Therefore very many phenomena will shew themselves

selves, which cannot be clearly understood or explained ; except when we shall have made a great number of experiments upon mixtures, of which however a perfect doctrine cannot be had because of their number, as will appear to every one that is conversant in the science of combinations. So that Philosophers will always be ignorant of the causes of some meteors.

But also very many different things mixed together produce motions that are much alike, and therefore in the upper regions like phenomena will often be exhibited by various exhalations. So that there will not always be the same cause for the same appearances.

§. 1183. And whereas great changes are made by reason of the very great motions in the secret bowels of the earth, and the dense or stony crusts are broken and removed, which before hindered the exhalations of some bodies from bursting forth ; but now the soil being broken through, and the jaws laid open, they can mount on high, raise new phenomena not seen or heard of before, which endure as long as there is any such matter to subsist them. But this being removed or consumed, they will again cease. Is it not from hence that some ages are more fruitful in producing strange meteors, and others more barren ? There will be also meteors that are peculiar to their own soil, and depend upon the different exhalations of different regions. Therefore to arrive at an accurate knowledge of meteors it is required, that every one should carefully observe and describe those of his own country.

§. 1184. Whatever ascends into the air from the earth, is called a *vapour* or *exhalation*. A vapour consists of any aqueous and moist parts. An exhalation consists of the subtilest parts of any

solid or fluid bodies, that are not aqueous or moist.

1185. A vast quantity of vapours and exhalations is continually ascending on high from the earth, with which as the atmosphere is filled and corrupted, it is necessary that many phenomena must arise. At *Utrecht* I found from many years observations, upon the evaporation of water in an open but shady place, that by taking a mean in about the space of one year it was equal to 29 *Rbinland* inches; from which the observations taken by M. *Sedileau* in *France* hardly differ^a; yet Dr. *Halley* found, that from a vessel full of water, and placed in *Gresham* college in such a manner, that the sun or winds could not well get at it, by the exhalation of a whole year only eight inches were lost. If we rely upon our observations, and suppose 29 inches to have evaporated, these floating in the air, and made at least 1000 times rarer, will possess a perpendicular altitude of 2416 feet. If half the surface of the earth is supposed to be covered with water, and a like quantity of water ascends every where, the whole atmosphere all round the earth would be filled with vapours alone, to the perpendicular altitude of 1208 feet. How many millions of butts of water under the form of vapour ascend in one day from the *Mediterranean* sea, the great *Halley* has determined by a fine experiment^b, so that the quantity of vapour that arises daily exceeds belief. The other part of the earth's superficies is every where thick with plants, except some sandy desert places. The plants perspire the greatest quantity of exhalations and vapours;

^a Memoir. Math. & Physic. A. 1692.

^b Philos. Transf. No. 189.

for according to the observations of the worthy Dr. *Hales*^a, an heliotrope $3\frac{1}{2}$ feet high in the space of 12 hours expired at least $1\frac{1}{4}$ of a pound, and therefore almost as much as the sun is used to raise in a day's time, from a surface of three square feet. If we admit of a like expiration from all the other plants, the vegetables will not send up a less quantity, than the vapours that arise from all the waters. Animals also perspire very much from their bodies; for the perspiration of an adult man is to that of the heliotrope before mentioned, as 141 to 100; and so it may be supposed of the other animals: for Dr. *Keil* observes, that in 24 hours a man expires 31 ounces; and Dr. *Hales* has observed, that the heliotrope perspires 22 ounces in the same time. Though we do not know the number of animals, that live upon the earth at the same time, yet we know it to be very great; wherefore the exhalations of animals will not a little contribute to fill the atmosphere. To which if we add the exhalations of vegetables, which are drying or rotting over the whole earth, also the copious fumes of bodies burning for daily use, as also of burning mountains, and likewise the various parts perspired out of the bowels of the earth, or thrown out by subterraneous fires; it appears that a vast quantity of exhalations and vapours is continually mounting into the regions of the air, which will supply a sufficient fund for the production of meteors.

§. 1186. Vapours and exhalations ascend upwards for various causes, of which these are the chief. First, earthly fire, subterraneous fire, and that of the sun, entering into bodies agitates their parts with a rapid motion, drives out of the bo-

^a Vegetable Staticks, §. 1.

dies the most subtile of them when parted from matter, and with great rapidity forces them upwards by the laws of percussioⁿ: also fire enters into the particles of bodies, and rarifies them. If therefore it has separated any of them from it's association with the rest, and then rarified them, so that those which before were of the same specific gravity as water, have acquired a diameter ten times greater, they will have 1000 times a greater volume, under which still concluding the same quantity of matter, they will be specifically lighter than air, so that they will ascend through it, till they meet with rarer air, and such as is of the same density as themselves: therefore the heavier the air is, the less rarefaction of bodies is required to make them ascend; and the lighter and rarer the air is, so much greater the rarefaction of the bodies must be. Therefore when the mercury is low in the *Torricellian* tube, few vapours ascend; but in greater plenty when the mercury is higher, as *Dr. Garden* has often observed^a. Again, fire dissolves bodies into very fine parts; if therefore it shall strike any the most subtil from the other mass, which because of their subtilty are lighter than the several particles of air, they may be carried up by the air, in the same manner as those that are specifically lighter. Again, many bodies being exposed to the same fire as air is, can receive more fire into them than the air does, and can retain it for some time. And whereas fire endeavours to be *in equilibrio* with all the neighbouring bodies and spaces, by §. 791, 793, as soon as it has forced the subtile parts of bodies from their company, and has entered more plentifully into their pores than in the contiguous air, it flies away with them into the air, and so much the more

^a *Philos. Transf. No. 171.*

rapidly,

rapidly, as the difference of equilibrium is greater, in the heat of the air, and of those parts in which they reside. But on this account the volatile parts are hurried away with their fire, as well side-ways as upwards; as we may see in an evening in clear summer days, when the vapour arises out of the ditches, and expands itself as well laterally over the adjoining meadows as upright; or in the time of frost at an evening, if we make a large aperture in the ice, a vapour of water warmer than the air will rise in great plenty out of it. Again, as often as the parts of bodies are separated by fire, and withdraw out of the sphere of it's attraction, they enter as it were into a sphere of repulsion, by driving one another away, by which means they are rendered volatile by the fire. If therefore this repulsion is according to the quantity of heat, as in some sort may be concluded, it easily appears why vapour may at all times issue from water, when exposed to the open air. For since by §. 729, the vapour of boiling water is 14000 times rarer than water, and the heat then is indicated at 212 degrees by *Fahrenheit's* Thermometer, supposing summer heat to be estimated at 91 degrees, the vapour will be 5943 times rarer than water. And putting the heat in this Thermometer at 32 degrees, the vapour will be 2113 times rarer than water: but air is generally 600 or 700 times rarer than water; therefore such vapour will be still rarer than air. So that in winter, from an aperture in the ice, a vapour may arise, and ascend into the air, as the event will inform us. Fire seems to be the chief reason, why particles from bodies fly aloft. For more water never ascends into the air than on a summer's day, when the sun is very hot. Also firm bodies in the fire become volatile.

Q 3

Secondly,

Secondly, not only the parts of bodies that are separated by fire acquire a force of repulsion, but likewise those that are separated from the rest by fermentation, putrefaction, permission, separation and effervescence. Therefore much vapour and exhalation is then used to arise from bodies, which are exposed to such actions. But that no doubt may remain, whether a volatility of the parts may proceed from separation alone, take notice whenever you see a river that falls down a precipice upon a rock which it dashes against, how much vapour arises from hence. In *Canada* the river *Niagara* falls down a steep rock of 156 feet high, with vast noise which is heard by all the country round about, and forms a cloud by the particles that fly off, rising in the form of a thick mist, which may be seen at the distance of five miles^a. *Cassini* tells us something like this of the fall of the river *Velino*^b; as also *Leopold* of the river *Giotha Elf* in *Sweden*^c.

Thirdly, air is attracted by water, and by many other fluids, and so there becomes a kind of solution. By a like action water and fluids are attracted by air. And therefore the parts of water and of other fluids attracted by air, as soon as they are separated from the masses to which they belong, will ascend into the air, and be there dispersed.

Fourthly, winds also raise many parts of bodies, but especially aqueous vapours, and hurry them away along with them. Hence wet cloths, when exposed to the wind, are soon dried.

Lastly, whatever can bring it about, that parts of bodies, when separated from them, shall become

^a *Philos. Transf. N. 371.*

^b *Memoir. Adopt. T. 6.*

^c *Relatio Epist. p. 97.*

specifically

specifically lighter than air, will be the cause of their ascent. If such particles have much less specifick gravity than air, and meet others that are heavier, to which they adhere ; they will compose a mass that is still specifically lighter than air, and which together with them can ascend on high.

§. 1187. That vapours ascend from the earth we discover ; first, when we see the ground and distant mountains to throw out a fume. Secondly, hills at a great distance, though in a serene sky, have their heads as it were in a cloud. Thirdly, all bodies at a great distance seem as it were to twinkle. Fourthly, vapour ascends out of lakes and marshes under the appearance of mist. Fifthly, the sun and moon, at their setting and rising, are very ruddy.

§. 1188. Because the density of the atmosphere, and therefore it's specifick gravity, differs at different distances from the surface of the earth ; vapours and exhalations may ascend to various altitudes. Those which are rarest, or repel one another with a great force, to the greatest distances. But those to the least whose specifick gravity hardly differs from that of the air : Or which have been urged upwards by a small motion, whether mechanical or that of repulsion. They arise to an intermediate altitude, the gravity of which is *in equilibrio* with the air of the middle region.

§. 1189. From all which it is plain why clouds are formed at different distances from the earth ; and other meteors now happen at a greater distance from it, and now not far from the ground. Also why when the density of the air changes in the same place, the exhalations there suspended either ascend or descend.

§. 1190. The denser the atmosphere is, so much the fitter it is for supporting vapours and exhalations; and the rarer the air is, so much the more unfit it will be. Now in winter the cold atmosphere is denser and heavier, as is proved by the barometrical observations of this climate. Therefore in winter the atmosphere can receive and retain the greatest quantity of vapours and exhalations, and therefore at that season the greatest number of meteors happens. And because this reason chiefly prevails in cold regions, it is from hence that more meteors are observed in these than in warmer climates.

§. 1191. Vapours and exhalations descend to the earth out of the atmosphere chiefly for these causes.

First, as soon as the density of the air, and therefore it's specifick gravity, is diminished on any account whatever, then the exhalations will no longer be *in equilibrio* with it, but prevailing by their gravity they will descend. This is proved by an analogous experiment. When moist air in a receiver is rarified by means of the air-pump, a little cloud is presently formed, which falls as soon as the air is farther rarified. Therefore we often observe rain, and other meteors, when the mercury in the barometer being very low, indicates the weight of the air and it's small density.

Secondly, when such things had ascended as were much rarified by fire, afterwards losing their fire they are again condensed, and become specifically heavier than air.

Thirdly, those things descend which have lost their motion they had received from fire, or from any other cause, by which they were driven upwards.

Fourthly,

Fourthly, when many particles are driven by winds against resisting obstacles, or by winds blowing with an opposite direction, or meeting one another by any other cause; by this course they will be made specifically heavier than air, and will therefore descend.

Fifthly, when some exhalations meeting one another are of such a nature, as to excite an effervescency, and then are precipitated, the same things happen as in chemical precipitations.

Sixthly, when being exhaled by the winds, they are together driven downwards with the air in which they inhere.

Seventhly, if the winds blowing with an horizontal direction, below that part of the atmosphere in which exhalations are suspended, drive the air out of it's place; then the upper part of the atmosphere, together with all it contains, descends into the place that was forsaken by the former air.

Eighthly, also the rays of the rising sun, meeting the exhalations, determine them towards the earth. And as they rarify the air at the same time, or make it specifically lighter, so much the more the exhalations descend.

Lastly, when more exhalations and vapours ascend than the atmosphere can contain, those that are superfluous return back, having lost their motion by which they ascended.

§. 1192. Meteors may be conveniently divided into three kinds. First, aqueous meteors, as *mists, clouds, dew, rain, frost, snow, hail, whirlwind, rain-bow, halo, parheli, paraselenæ*, &c. Secondly, fiery and shining meteors, as *auroræ boreales*, with their various species, *falling-stars, ignes fatui* not burning, others *inflamed, lambent fires, bolis, blight, lightning, thunder-bolt, thunder*, &c.

&c. Lastly, airy meteors, as *winds*. In this order I shall briefly discourse of these meteors.

C H A P. XXXIX.

Of watry Meteors.

§. 1193. **W**HENEVER vapours or exhalations are in the atmosphere near the earth, in such plenty or in such manner constituted, that they intercept much of the light, and make the air darker than usual, we then say there is a *mist* or a *fog*.

§. 1194. Mists are formed by vapours and exhalations, which ascend slowly from the earth, or fall towards it very slowly from on high, so that they seem to be suspended in that place, and hardly to advance. When they are composed of vapours, the mists are moist and wet, and then they are not hurtful to the health of animals, or offensive to the smell. But they that consist of exhalations often stink; some are hurtful to health, and the causes of many diseases, and many are poisonous and deadly. It is plain that mists are composed of other matter than aqueous vapours, because sometimes after them there is seen swimming upon the surface of the water a kind of little skin or film, which is greasy and reddish, like to that which chemists observe, when they prepare the golden sulphur of antimony.

§. 1195. Mists are formed in a quiet sky, when no wind is stirring, and never when the wind is any thing violent; for by that they are discussed and dispersed. They are generally observed in an evening, especially if the sun in the day-time has much heated the earth, which at his setting quickly cools again. Because then the heated

parts

parts of earthly bodies are compelled to ascend in great plenty. In *Holland* this chiefly happens in spring and autumn, but seldom in summer. Because there is less difference between the evening heat, and that of the day, in the air of summer, than in that of spring or autumn. Also there are mists in the morning at sun-rising, when the air is sooner rarified by the same heat, than the exhalations which are suspended in it, which therefore descend as being specifically heavier than the air. And they are partly driven downwards by the beams of the sun. They are oftenest seen in the winter months, *November, December, January, February*; seldom in the summer months, because of the coolness of the atmosphere, that suddenly condenses vapours and exhalations. Hence if you do but breathe in the winter you see a mist, of which there is no sign in the summer. Therefore in places near the north-pole there are mists for several days together. They generally happen before or after the west or south wind, or the east, rarely with other winds; for they bring us many vapours from the neighbouring ocean. Mists happen in a hard and continual frost, and when the weather is clear and mild.

§. 1196. If mists continue for several days successively, they are often immediately followed by rain or snow, the vapours then condensing into grosser bodies.

§. 1197. Mists are observed to happen when the mercury in the tube has either a low or a high situation. They happen when the glass is high, after the heaven has continued calm for a good while, and in the mean time great plenty of vapours and exhalations have been accumulated, making the air dark by their quantity, and disorderly

orderly position of their parts : Or because the exhalations by their gravity begin to subside through the sluggish air. There are mists when the mercury is low, when not long before the heaven was calm, nor continues so afterwards, but lets down it's contents, which because of it's rarity it can now no longer contain. And this is proved by an experiment mentioned §. 1191. N^o. I.

§. 1198. When a thick mist falls down upon the earth, it moistens it like rain. For it consists of the same vapours as this does, but only thinner, and which also differ in magnitude. Sometimes they are too subtile to be seen, and sometimes they are larger like small drops : So that it is no wonder that a whitish rain-bow may be seen in them, such as has been observed by *Dechales* *. A mist falls indifferently upon all bodies, whether rough or polished ; sometimes if it be very moist, it penetrates into houses, clings to the walls and all kind of furniture, and runs down in drops.

§. 1199. Mists intercept the day-light sometime more and sometimes less. Sometimes it causes so much darkness, that persons very near can hardly see one another. This darkness of the air depends on the disorderly situation of the parts, which causes passages of an irregular figure and magnitude ; as also on the very different density of the air and the exhalations. By this it happens, that while the light endeavours to pass it is unequally attracted, and being turned out of it's strait course is hindered from passing. Hence it often happens, that when the air is clogged with but few vapours, it appears dark and misty ;

* Tract. de Meteoris, §. 4.

but is transparent again as soon as the air receives more vapours, which are distributed through it more uniformly.

§. 1200. Sometimes the mists are very thin, and dispersed equably through the great region of the atmosphere, something intercepting the rays of light. Then when we look upon the sun, he does not offend our eyes, but appears pale, without radiating beams; and yet the atmosphere looks of it's usual sky-colour, as if the heaven were almost serene.

§. 1201. Does not serene weather follow morning mists in the summer-time? It is because of their rarity and small quantity they are easily expelled out of the atmosphere, or by means of the sun-beams they are so attenuated, driven away, and dispersed, that being entirely resolved into very little particles, they are distributed quite through it.

§. 1202. Do not many and sudden mists arise from mountains, from winds striking against them, and condensing the vapours, which though rare and scattered they carried along with them?

§. 1203. To a spectator that stands in a valley, why do mists seems to arise out of the sides of mountains illuminated by the sun, which are thick like smoke rising out of a chimney? For no other reason but because the spectator views the sun-beams laterally and obliquely, that strike against the mountain, through which the ascending vapours may easily be seen. As we see small particles of dust, floating in the air and the beams of the sun, when we look upon them sideways.

§. 1204. A *cloud* is nothing but a mist, but suspended higher in the air above the earth; therefore an ascending mist seems to be turned
into

into a cloud. This plainly appears if we look upon the smoke that arises from the burning of any bodies, which immediately forms a cloud.

Secondly, all the travellers that have had the curiosity to go up into the clouds hanging on the tops of mountains, have observed them to be mists only; as we have been told by such eye-witnesses as *Cabæus*, *Froelichius*, *Sturmius*, *Marriot*, *Dechales*, *Lamy*, *Frezier*, &c. nor has it ever been found that they consist of snow, ice, or any firm body.

Thirdly, their shape is liable to continual changes, which could not be except they consisted of thin and fluid exhalations, and not of solid and concrete bodies.

Fourthly, if clouds should coalesce into firm masses, they must acquire a much greater specific gravity than the air has, and therefore would immediately fall by their own weight, unless they were supported and hurried away by very rapid winds. When at rest they must fall by their own gravity, which we find not to happen by the clouds, though they seem very solid, as daily experience testifies.

§. 1205. Yet clouds appear to be more opaque than mists, and the whiter of them seem to be no other than pure snow, or some white and solid bodies. But this appearance proceeds, not from any different constitution of the parts between a cloud and a mist, but because the spectator, when surrounded with a mist, receives the light after it has entered the mist: whereas when he looks upon a cloud, he takes in at his eyes the light that is reflected by it's external parts, which is very strong and copious; much more strong and copious than that before transmitted.

§. 1206. Clouds are suspended in the atmosphere at different heights. Sometimes there is one over another, according as their various specific gravity is *in æquilibrio* with the circumambient air. Such clouds are easily known from the different directions with which they move. The highest of all hardly seem to arise to an height equal to that of the highest mountains. For to those that have viewed them at a distance, many mountains seem to raise themselves above the clouds. Secondly, many that have ascended to the tops of mountains have observed, that the clouds moved below them, and not above them. Thirdly, *Ricciolus* found by a geometrical mensuration, that the highest clouds never arose to 5000 paces; and *Kepler* only to a fourth part of a *German* mile. Yet perhaps some very thin exhalations may arise to a greater altitude, as from some of the northern lights has been conjectured by some. And if a vapour of water can be so far rarified, as to take up 14000 times a greater space than before, it will be 60 times rarer than the air that is near the earth. But air at the distance of 14 *British* miles from the earth, according to the law of elasticity, would be 60 times rarer than at the superficies; so that if vapours or exhalations like these in rarity, should not be condensed in their ascent through the air, by the laws of equilibrium they might be raised to 14 *British* miles.

§. 1207. The figure and magnitude of the clouds is changing every moment; for the air with which they are surrounded is never quite at rest; therefore parts are continually separating from them, and others approaching towards them. For if any sensible wind blows, which reaches the cloud below or above, great parts will be perpetually torn from it.

§. 1208.

§. 1208. The extremities of clouds are very irregular and uneven as it were; from whence it follows, that a cloud is not a body consisting of conjoined and united parts. For an united fluid that swims in another fluid must assume a spherical figure, which would continue if that fluid were converted into a solid.

§. 1209. The bigness of the clouds is very different; for some are small, but there are others, as *Mariot*^a has observed, which are above a mile long. Some are very gross, as may be concluded from the quantity of rain that falls from the same cloud. This I have observed to be sometimes equal to the height of one inch. From whence we may conclude, that the thickness of the same cloud was above 100 feet.

§. 1210. Philosophers have disputed, whether the upper and lower surfaces of clouds are plain or uneven. Certain it is that both may obtain. But the parts that are most extant are first torn away from the rest by the violence of the winds.

§. 1211. The clouds are often hurried away by the winds with a very swift velocity; so that in the space of one hour they may travel 6 or 7 *Gallick* miles. Sometimes they are so crumbled into pieces by the wind, as immediately to vanish. Hence sometimes when tempests rage the heaven is clear. Sometimes the clouds are so dispersed, as to vanish out of sight, when the beams of the sun attenuate the grosser vapours, of which the clouds were composed; by which they not only ascend, but are distributed through other air, so as to become transparent with it. Sometimes a cloud thus constringed by the sun has been seen to send forth as it were a rising smoke, and so

^a Movement des Eaux. C. 3.

was transferred to the higher clouds. Clouds are also dispersed when the weight of the air is increased. For then they ascend, that they may be *in equilibrio* with the higher and thinner air; and thus being brought into purer air, they are dissolved and melt away insensibly.

§. 1212. Sometimes we see clouds that are tinged with various colours, yet generally they appear white, because their external parts reflect the pure light of the sun, not separated into it's colours. Other clouds are brown and black, as in particular when it thunders, which then absorb the light within themselves, and hardly reflect it at all. In the morning and the evening, at the rising and setting of the sun, the clouds appear red, which when the sun is nearer the horizon appear violet, and afterwards blue. These colours arise from the light that strikes upon the transparent globules of vapour, enters them, and then being reflected, and then refracted, parts into colours; of which now the red, then the violet, and then the blue, strike the eye, according to the various altitude of the sun, something like as it is in the rain-bow. Hence it may be understood why the clouds may sometimes appear green, such as were seen by *Frezier's*, and are described in his voyage to the *West-Indies*.

§. 1213. When the mercury subsides in the baroscope, why is the heaven cloudy? Is it not because when the mercury subsides, it indicates the atmosphere is become lighter, and unfit for supporting exhalations? These therefore descend, are gathered together, and make the heaven dark and cloudy.

§. 1214. The clouds are of great use. First, for conveying the matter of rain to all the regions of the earth. Secondly, for covering the earth,

that it may not always be parched by the heat of the sun; and thus the vegetables may have time and opportunity for digesting their nourishment. Thirdly, the clouds seem to be the principal causes of winds. Fourthly, that the light of the sun may be reflected to the earth in very different directions, by which means many bodies may be seen, which are not directly illuminated by the sun.

§. 1215. Steams and vapours of the earth, that by reason of their rarity cannot be seen, ascending on high like a mist, or again lighting upon the ground from the air, are called *dew*.

§. 1216. Certain watry drops are gathered night and morning, on the several parts of plants that are exposed to the air, which have been called *dew*. And it has been thought that this vapour fell by night from heaven, and was collected by the leaves of plants, and that this only was dew. But many and accurate observations have proved, that these drops are only the sweat of plants, which continually expires through the orifices of their vessels. For every plant emits this dew after it's own manner, according to the different structure of the vessels, and the situation of their orifices^a. Secondly, plants that were shut up in vessels and covered, have collected a greater quantity of dew in a night's time, than those that stood in the open air. Thirdly, the drops are gathered only in those places, where the orifices of the vessels are manifestly open, and not all over the leaf; nor in the lower places, as must be if it arose from ambient and distilling steam or vapour. Indeed this sweat of plants perpetually exhales from the same vessels, but is carried away and dispersed either by the wind, or by the heat

^a Gersten. Tentam. de Rore.

of the day. At night after a hot day, and in the air without wind, it is emitted copiously from the vessels, is collected, nor vanishes into air, before the rising-sun heats the liquor, and makes it volatile.

§. 1217. The sun by his beams penetrates into the earth for some certain space, and there warms every thing, rarifies and agitates it, and makes the particles mount aloft. Whatever rises in the day-time escapes our sight, and is soon distributed through the air. But when the air grows cool after sun-set, and all night long, the warm steams in greater plenty proceed to ascend out of the earth with a slow motion; so that sometimes they are raised no higher than 31 feet in the space of an hour and half, and adhere first to bodies that are near the ground, and then to those that are higher.

§. 1218. This ascending dew is different according to the different constitution of the place and soil; here it will be more watry, there it will more abound with spirits, oils, salts, metals, and with other bodies of very different sorts. Therefore being endued with different properties, it will excite various phenomena, and occasion distempers to animals. Hence there are some countries, in which dew never touches or falls upon polished metals, or certain other bodies, being repelled by some, and by others attracted, with great but with different forces, and being collected it adheres to them in great plenty. There are other regions of the earth, in which dew is attracted by all bodies without exception, and seems to slip upon all when exposed to the open air.

§. 1219. There are places in which dew is observed only to ascend aloft, and not to settle.

There are places in which it both ascends and settles. But it is carried upwards in greater plenty than downwards. Being drove on by the winds, by which it is either condensed, or so dispersed that it disappears.

§. 1220. It is not easy to assign the quantity of dew that arises every night, or in the whole year, because of the winds, the rains, and other inconveniences. This will also differ in different countries, according to the constitution of the soil, the situation, and the heat communicated to it by the sun.

§. 1221. Because the dew consist of very different exhalations, gathered in various places, and at a different season of the year in the same places, it will have different contents, as waters, strong-smelling spirits, salts, oils, earths; as the chemists have found by experience.

§. 1222. In the summer, when the sun violently heats the trees and herbs, oils are also raised from them, which falling upon the earth make what is called an *oily* or *honey-dew*. This falling upon water floats on it's surface, and makes it fat. I have seen this to have fallen on very hot days commonly before noon, but in places in which trees were planted.

§. 1223. *Rain* is a multitude of small watry drops, falling from the upper air at different seasons.

§. 1224. Rain almost always falls out of clouds; yet I have seen rain, but in small quantity and small drops, that fell out of the air, that was obscured by no cloud, in summer time, when the heaven had been calm for some time, and the heat was violent and even suffocating. More vapours therefore were raised by this, than could be supported by the air; which presently when the

the heat abated were condensed, and then fell down again.

§. 1225. Rain is formed when the particles of vapour which compose the cloud approach nearer to one another, so that they can attract one another, be constipated, gathered together, coalesce, and form a drop; which being specifically heavier than the ambient air, falls down and meets with other drops or aqueous particles, is united with them, and so increases to that magnitude which it has when it falls upon the earth.

§. 1226. If the whole cloud in all it's parts is changed equably, but slowly; so that the vapours go together gradually; they will fall away in very little drops, the specifick gravity of which will hardly differ from that of the air. The little drops will then descend through it gently, and will form a very thin and dewy rain, or what is called *pssecas*. This happens sometimes, but not frequently. The same will happen also, when the cloud shall begin to change at it's lower part, and the change shall proceed gently upwards. For then the vapours uniting into small drops will descend gently, and come to the earth of the same magnitude as when they left the cloud.

§. 1227. But if the upper part of the cloud be first changed, and the change proceed gradually through the middle till it comes to the lower part, the small drops will first be formed in the upper part of the cloud, which falling upon the lower will unite with them, and so continually increase the farther they fall. This is very frequent, and has been observed by some, who being in a vale have found a great shower, but going up a hill in the same cloud, have there found lesser drops of rain, and so much the less the higher they ascended.

§. 1228. In §. 1191 we assigned the reasons why all meteors, and therefore the particles of clouds also, fall down from on high. Yet the chief cause of rain seems to be the winds. For first, they blow downwards upon the cloud, condense it, and force the vapours into union; or, secondly, they drive vaporous clouds, arising out of the ocean, to terrestrial regions, and make them dash against high ground, hills, and woods, and so force them into rain. Therefore mountainous countries are better watered with rain than such as are flat. For in *Lancashire* in *England*, which abounds in high mountains, according to *Townley's* Observations, there fall yearly about 41 inches of rain; whereas at *Upminster* there are collected only $19\frac{1}{2}$ inches, by *Mr. Derham's* Observations. Thirdly, as mountains oppose the clouds, so the winds blowing with a contrary direction against others, will compress the clouds. Whence in the *Ethiopic* ocean, over-against *Guinea*, sometimes showers fall by pail-fulls. Likewise in these regions, after any wind has raged, as soon as by opposition it is reduced to rest, the intermediate clouds compressed by both are dissolved into rain. Fourthly, because the greatest quantity of vaporous clouds are formed from the ocean, the winds that drive them from the ocean to our regions are particularly rainy; whereas other winds that blow upon the continent, and bring clouds from thence, are seldom observed to be rainy. From notes taken for the space of some years, compared with one another, at *Utrecht* for the same time the rainy winds have been 203 west winds, 135 south-west, 61 south winds, 27 south-east winds, 32 east winds, 29 north winds, 54 north-east winds, 61 north-west winds. The western breezes blow from the *German* ocean, and are there-

therefore so rainy; partly from the same ocean, and partly from the large mouths of the *Schelde*, the *Maes*, and the *Rhine*, the north-west winds blow, and are therefore so moist. The northerly winds are cold, and do not bring with them such a quantity of clouds. Hence they are less moist, though otherwise they would be the moistest of all, since they blow from the *German* ocean, and the *Zuyderzée*, but generally without clouds.

I have also observed, that at *Utrecht* every year the rainy days are in proportion to the dry ones, as 5 to 12. But all these things are peculiar to every country, and can only be known from particular observations.

§. 1229. Because rain falls from on high through the air, which is always infected with all sorts of exhalations, it unites them with it like a lixivium, and brings them to the earth; therefore rain will not be pure water, but blended and defiled with salts, spirits, oils, earths, metals, &c. Of these ingredients there will be a great difference, according to the difference of the exhaling soil, and the different season of the year. Hence rain-water in spring above all others is subject to fermentation. It is more impure after a long drought and heat, than when one rain comes soon after another. *Boerhaave*, a most experienced Philosopher, found that to be most impure, which falls in cities, or in low stinking places, in hot and windy weather ^a.

§. 1230. The seeds of very small plants, and the eggs of innumerable insects, float in the air, which fall down together with the rain. Hence it is that the green river weed vegetates in it,

^a *Chemiæ*, Vol. I. p. 597.

and innumerable animalcula and worms are hatched, which die and stink, and the rain-water is corrupted. That which falls in the sea is not so impure, because the air incumbent on the ocean is not so much impregnated with exhalations.

§. 1231. By reason of the various corpuscles which are mixed with the water, if rain be preserved in a vessel which is never so carefully closed up, in a short time it will be full of small white spots or clouds, which by degrees become greater and more and more opaque. These afterwards degenerate into a thin, stiff, glutinous mucus, and change the water into a ropy matter. Since therefore rain brings with it to the earth such a variety of bodies, it can be no wonder that such a diversity of plants are nourished by rain-water, the juices of which are so different from one another.

§. 1232. From these we may partly account for those showers that are related as prodigies; for with those the several exhalations have at the same time been let down from the atmosphere. *Moses* has taken notice ^a, that it rained brimstone; which is mentioned also by *Spangenbergius* ^b, to have happened in the dutchy of *Mansfield*, An. 1658; and likewise at *Copenhagen*, An. 1646, by *Olaus Wormius* ^c. Also at *Brunswick*, An. 1721, by *Siegesbekius* ^d; where it rained a burning substance, which could not be extinguished either by water or motion. *Scheuchzerus* relates ^e, that An. 1677 there was a yellow rain, in the form of

^a Gen. xix. Deut. xxix.

^b Chron. Mansfield. T. I. p. 395.

^c Museum, Cap. XI.

^d Nova literar. An. 1684.

^e Meteorolog. Helvet. p. 14.

powder swimming upon the lake near *Zurich* and the neighbouring wells. It was thought this powder was brought by the wind from the blossoms of the pines, which mingled with the rain.

Frequent mention is made, both by the ancients and moderns, of drops of blood falling in showers, so that we may not doubt of the truth of it. When *Peirescius* examined such a shower that fell in *France*, he found the drops were full of red insects ^a. Also the excrements of some insects are red, as is certain as to that of butterflies. These mixing with a shower of rain, may make it seem to rain blood.

A salt shower has been observed, at the time of the raging of a tempest in *Sussex* in *England* ^b. The wind raised the sea-water, as it dashed against the rocks, and carried the small drops aloft, which then fell on the neighbouring land. A fat and butterish shower fell in *Ireland* ^c, An. 1695. It was clammy, soft, deep yellow, melting in the hand, and would dry up and grow black at the fire. But it must be a mere fable, when it has been said to rain iron, wool, stones, flesh, or milk.

§. 1233. Therefore because rain washes the air of it's impurities, we may always observe, that after a shower of rain the air is most pure and transparent, so that very remote objects may be seen most clearly, and the colours of plants are most bright and chearful, and the whole vegetable world is as it were renewed.

§. 1234. The drops of rain are spherical, of different magnitude. Sometimes they are full, sometimes small, and their diameter seldom ex-

^a Gassend. in Vit. Peires. L. II. p. 156.

^b Philos. Transf. N. 289.

^c Philos. Transf. N. 220.

ceeds a fourth part of a *Rhinland* inch : Unless when showers have poured down, the drops of which are said to have been an inch in diameter^a. These depend on the attracting force of the parts in water, as also on the resistance of the air through which it moves.

§. 1235. Why is rain sometimes dense and sometimes rare ? Does not this depend, *ceteris paribus*, on the different thickness or altitude of the cloud, so that the most dense rain proceeds from the thickest cloud ; as also on the various density of the cloud ? Why are the drops greater and rarer in summer, but in winter less and denser ? Does not this depend on the different density and resistance of the air through which they fall, which are less in summer than in winter ?

§. 1236. Though rain falls from high clouds, yet it does not come to the earth with so great velocity, as would follow from the law of gravitation, because of the resistance of the air. This is so ordered, that the tender parts of plants might not be hurt by the drops, which otherwise would be destroyed.

§. 1237. Why does it only rain by vapours, and very seldom, if at all, by exhalations. Is it not because vapours are much more frequent and copious than exhalations, and very easily are formed into drops, and by falling are mingled with exhalations ? These likewise are generally consumed by being set on fire.

§. 1238. In these regions the rain falls very irregularly, and by no means at any stated times. By comparing a great number of years together, for one year at a medium the altitude was at *Utrecht* 24 *Rhinland* inches. This quantity therefore differs in different countries. At *Harlem*

^a Aët. Lips. Sulp. T. I. p. 425.

and at *Lisle* in *Flanders* the same quantity has been observed to fall. At *Delf* and *Harderwick* 27 inches. At *Dort* 40 inches. At *Middleburg* in *Zealand* 33 inches. At *Paris* 20 Paris inches. At *Lyons* 37. At *Rome* 20 inches. At *Padua* $37\frac{1}{2}$. At *Pisa* in *Italy* $34\frac{1}{4}$. At *Zurich* in *Switzerland* 32 inches. At *Ulm* in *Germany* $26\frac{3}{8}$ inches. At *Wittenberg* $16\frac{1}{2}$. At *Berlin* $19\frac{1}{2}$. In *Lancashire* in *England* 41 inches. At *Upminster* $19\frac{1}{2}$ English inches. From whence it is to be collected, that it is a dry year when a less quantity of rain falls in these places, and on the contrary, a wet year when a greater quantity falls. This difference arises from the neighbourhood of seas, lakes, rivers, mountains, forests, from the winds, and from other concurring causes.

§. 1239. The use of rain is, first to moisten and soften the earth, which the sun dries up ; to make it fruitful that it may produce and nourish the plants. Secondly, to wash and cleanse the air from all filthy exhalations, and the hurtful or useless respirations of animals. Thirdly, to moderate the heat of the air that is near the earth ; for the rain falls from the higher and cooler air. Fourthly, rain is the origin of fountains, springs, and brooks, and therefore of rivers, though not the only cause ; for to this the vapours concur, which cooling by night, and carried to the elevated surfaces of mountains, are there united, and converted into water ; which distilling downwards, supplies an incredible quantity of water for springs and rivers.

§. 1240. It sometimes happens, that two winds with parallel and opposite directions, and being but little distant, squeeze an intermediate cloud, and suddenly condense it into water. But because of the opposite motion on each side, they
whirl

whirl it about, make it turn round without end, so that the cloud being carried about is sucked into itself, and a vortex or whirlpool is made. Just as if they had struck the circumference of some intermediate wheel with an opposite direction on each side, by which means it would acquire a rotation about it's center. The revolving part of the cloud, thus being made a vortex, by it's gravity sinks downwards, and forms a cylindrical or a conical column, which by it's larger base still adheres to the remaining thick and black cloud, it's vertex looking downwards. It is of different thicknesſes, ſometimes of 50 fathoms or more, and ſometimes hardly of 4 or 5. It is called *columna*, or *præſter*, or *watry whirlpool*, in

Tab. 25. *Greek* πένσις, ^a in *Dutch* een Hoos, in *French* Trombe
Fig. 4, 5, *de Mer*, in *Engliſh*, a water-spout, or whirlpool.
6, 7.

§. 1241. Such a whirlpool has been obſerved empty of water within, the parts receding from the center becauſe of the centrifugal force. In the internal hollow ſuperficies it reſembles *Archimedes's* ſcrew aa, becauſe of the water falling from on high and whirled about. The particles of water flying off from the external ſuperficies form rain. It is hurried away very ſwiftly by a powerful wind, and is carried over ſea and land. If it is over the ſea, and ſinks down almoſt to it's ſurface, a ſmall column B will be raiſed by it, riſing by the preſſure of the atmosphere to the middle of the *turbo*, in which the air is rarified by the centrifugal force of the water; whence light bodies are manifeſtly obſerved to aſcend through the middle of the *turbo*. Now ſince about the column ariſing out of the ſea a vaſt quantity of water of the ſpout falls on all ſides

^a Lucret. L. VI. V. 423.

with violence, the particles dashed out of the ocean by spreading on all sides exhibit the appearance of a thin rain C, so that the sea seems to foam and rage there. Where-ever the *turbo* settles, it strips the ground, destroys and beats down all things it meets, as buildings, trees, ships, with greater violence than the most rapid winds. It sends forth a terrible noise, like that of a multitude of carriages swiftly rolling over pavements of stone. Nor does it cease till the cloud is quite fallen down. The greater the *turbo* is, the sooner it is spent. Nobody has seen a water-spout that lasted for a day, no nor an hour; so wonderful is it's velocity, and short it's continuance.

§. 1242. Hence it may be perceived what we are to think of an *exhydria*, or what is called a *breaking of a cloud*, and how an immense quantity of water may fall upon the earth in a very little time, and overwhelm it with immoderate showers: Whenever the clouds are condensed by impetuous winds blowing with opposite directions; so that being immediately squeezed together, the particles of water fall downwards by their gravity. And because the wind may perform the same thing, by pressing the clouds against an opposite mountain; it appears why in mountainous places such breakings of clouds happen more frequently, than in flat and champaign countries.

§. 1243. If the dew that by night exudes out of the vessels of plants, or a vapour rising out of the earth, and adhering to the ground or the surfaces of all low things, in winter by means of the cold air bringing freezing particles, shall be changed into ice covering the faces of the plants and earth, it is called a *hoar-frost*.

§. 1244.

§. 1244. This is also observed to happen, when a mist creeping close to the earth surrounds bodies, clings to them, and presently a frost following turns the aqueous particles into ice. This adheres to bodies under the form of very small corpuscles, or the finest embroidery of snow-work. Such a hoar-frost is described by Mr. *Dechales* *.

§. 1245. This is sometimes seen in bodies, which are exposed to the open air; when in winter time, after a frost going before, the moist and warm air approaches to bodies, whose vapours are condensed, and applied to bodies that are cold and full of frost, when they are immediately turned to ice. This chiefly appears in the glass of windows, because glass attracts water very strongly. It appears also on stone-walls and houses, which seem to contract a kind of hoariness.

§. 1246. If a cloud is turned into rain, which as it falls passes through air abounding with freezing particles; the drops will harden into globular frozen bodies, which are called *hail*.

§. 1247. Hail is commonly of the magnitude of drops of rain; and as these drops are different, so the bigness of hail-stones is different also. Because those drops of rain are small which are formed in the upper part of a cloud, by §. 1226. so the hail stones will be least which fall upon the tops of mountains, and they will be of the larger kind which fall in vallies. Hence it was that *Scheuchzer* observed very small hail-stones upon the top of the *Alpes*. And that the same thing happens in other mountains, we have the testimony of *Fromond*, and other observers.

* Tract. de Meteoris, Pr. 4.

§. 1248. Hail-stones are seldom in the shape of a perfect sphere, but are generally here and there flat, compressed, full of angles, concave; and they are chiefly so, if they fall when the wind blows hard. For these arise from the winds, that by unequal pressure reduce the drops of rain to various figures, which they retain by congelation. Sometimes the hail is soft, and has it's superficies as if sprinkled with meal. But this is small, and soon melts, generally falling when the sky is calm, moist, and warmish. Hail has often in it's middle an opaque white nucleus, which is covered by a hard transparent shell. This nucleus seems to be first produced, and falling into a drop of rain, is surrounded by it, and then turns it into ice. This kind of hail generally falls with a mixture of rain.

§. 1249. Sometimes it hails great fragments of ice, and in no small quantity, the magnitude of which equals that of a pigeon's egg, or even of a hen, or goose. Nay, some have fallen so large, as to be half a pound weight, three quarters, or a whole pound. The annals preserved in *Europe* of such wonderful hails, acquaint us, that they have happened in summer, in the months of *May, June, July, August*, at the raging of a tempest, which condensed the clouds into a black spissitude, with great darkness, and a terrible bellowing of thunder, and flashings of lightning. Therefore the winds condensed the clouds, and changed them into an aqueous mass, which when left to themselves presently fall down in the manner of the breaking of a cloud, §. 1242. But the thunder arising from the nitrous and sulphureous exhalations set on fire, fill the air with spirit of nitre, which brings on a terrible cold, as soon as it meets the congelating particles

cles then floating in the atmosphere, §. 748. Through this air thus qualified, the force of the cold binds up with hard frost, the shower falling from the cloud, and therefore all that water is immediately fixed into ice, of a greater or less bulk, according to the quantity that unites into a mass. Such kind of hail makes great havock, by beating down the corn, and other vegetables, by shaking down the fruit, and even breaking the boughs of trees, the roofs of houses, windows; killing beasts in the field, and birds in the air, and men themselves that are exposed to their shock.

§. 1250. Hail sometimes puts on very different figures, and sometimes the same figure in all it's grains or stones, which is either conical, or pyramidal, half round, full of angles, or squeezed flat. Does not this depend on the congelating exhalations, which are of a different nature because of other bodies mingled with them, and which turn the water into ice under the form of different crystals, which at a certain time are of the same figure?

§. 1251. Why does hail fall seldom or never in vales so situate, as to have mountains to the east? Is it not because of the great quantity of sun-beams reflected from the mountains, which dissolve the hail as it falls?

§. 1252. It does not often hail at *Utrecht*; the observations of some years compared together plainly shew, that in each year it has hailed only eight times. I never observed hail when the east wind blew, and but once with a south wind. In the space of five years I observed how often it hailed when several winds blew.

§. 1253. As long as it hails, and before the hail comes to the ground, sometimes a noise and crackling

crackling is heard in the air^a; because some of the hail-stones are driven by the wind against others, which being very hard give a sound, like the clashing of two hard bodies. Likewise they strike such other hard bodies as they meet with, and thence proceeds a sound.

§. 1254. If a watry vapour falling from a cloud by congelation is changed into oblong filaments, which laid upon one another in various manners form flocks or fleeces, it composes that body which we call *snow*.

§. 1255. The figures of these flocks are different, being either regular or irregular. Sometimes they are thin oblong spikes, as A B, Fig. 1, Tab. 24. which have hardened as it were from the particles of vapour, Fig. 2. being disposed in a right line, and so falling are heaped upon one another. If the spikes lye in a very disorderly situation in respect of one another, and here are shorter, there longer, and have so grown together, an irregular fleece of snow is produced. But regular fleeces sometimes have the likeness of a hexagonal star with thin rays, which comprehend angles of 60 degrees, as in Fig. 3. where the 3 spikes A B, Fig. 1. fall on each other and grow together. Sometimes the snow is like a lily, Fig. 4. yet hexangular. Sometimes every one of the six rays is adorned with six other smaller rays, Fig. 5. I have seen snow the figure of which was as in Fig. 6. Sometimes the little flocks have resembled branches of trees, as Mr. *Cassini* has observed^b. Sometimes stars of 12 rays have fallen, and of other figures, which Mr.

^a Lucret. l. 6. v. 155.

^b Memoir. de l'Acad. Roy. An. 1692.

Hooke has elegantly delineated ^a. I think it proper to add 20 other figures of fleeces of snow, which the learned and industrious *Dr. Stokke* observed and accurately delineated, which fell in a very severe winter, An. 1740, at *Middleburg* in *Zealand*. *Mr. Kundman* collected and described many of like and different figures ^b. Whenever it has snowed oblong spikes or hexangular stars, they have brought with them very intense cold, which followed within a few hours. Snow of a regular figure is not common; and that is most frequent which consists of irregular fleeces, and of various magnitudes. The difference seems to depend on the different congelating exhalations, which are mingled with the vapours falling from the cloud; just as salts dissolved in water are crystallized into various figures. For otherwise it can hardly be conceived, how at some times all the fleeces should be formed in the air of the same regular figure.

§. 1256. A mass of snow just fallen is generally very rare, but that which falls in great flakes is not so rare as the other. *Sedileau* found ^c, that a heap of snow 5 or 6 inches deep, when it melted gave one inch of water, which *de la Hire* ^d has confirmed. He adds, that in the year 1711, he observed the snow to be as rare again as usual, and that 12 inches of snow yielded only one inch of water. *Weidler* tells us ^e, that in the year 1728 he observed snow, that was 9 times rarer

^a Micrograph. pag. 88. and Fig. 7. ad Fig. 27.

^b Rarior. Nat. & Art. S. 2. A. 21.

^c Memoir. Mathem. An. 1692.

^d L'Hist. de l'Acad. Roy. An. 1712.

^e Observat. Meteorol.

than water. In the year 1729 at *Utrecht* I examined the starry snow, which I found 24 times rarer than water. If snow falls plentifully in any place, and frost continues with serene weather, it will perpetually subside, and continually decrease by evaporation, till at last it entirely vanishes into air. For the sun by it's heat continually softens and melts it, makes the dissolved parts volatile, and thus consumes it.

§. 1257. If it snows while the frost lasts, the flakes will always be less; but if the air is warm, the flakes will be greater. Nay, sometimes they even fall along with rain.

§. 1258. Some have been persuaded, that it cannot snow in a hard frost, but this is contrary to experience. It was plain in the years 1729, 1740, and 1741, that it snowed upon some days during a hard frost, and even when it increased. Nor does the frost always remit when it snows, though that often happens. For I have observed, that the cold increased when the snow was down. Also that opinion is erroneous, that it never snows at sea; for this is frequent in the northern ocean.

§. 1259. As sometimes a vast quantity of rain has fallen in a certain place, so likewise of snow. Hence it was observed in the month of *February* of the year 1729 upon the borders of *Sweden* and *Norway*, as it were at one stroke, so great a quantity of snow fell, that it buried above 40 houses, and suffocated all the inhabitants. Something like this happened in *Silesia* and *Bobemia*, as we are informed by the learned *Wolfius*. The excellent mathematician Mr. *Maupertuis* has told us, that there are dangerous and destructive tempests of snow in *Lapland*. The wind blows all manner of ways, and drives the snow with violence

lence into the high ways, where it covers and choaks the travellers.

§. 1260. Snow is generally very white; and very strongly reflects the light that falls upon it, though it be a species of ice, of which every little particle taken by itself and viewed through a microscope is transparent. But since very irregular pores are left between the several *spicula*, the light because of the strong attraction of the *spicula* cannot pass through them, but is very strongly reflected; as it were by transparent glass beaten into powder.

§. 1261. The use of snow is this. First, to preserve the herbs in winter against the severity of the frost, by burying them under the snow. Secondly, to supply water to brooks and rivers. And hence in *Europe*, in the months of *April* and *May*, in many places the rivers swell by the melting of the snow on the mountains.

§. 1262. Sometimes in the heaven appears a bow of various colours, called a *rain-bow* or *iris*; when the sun shines behind the spectator, and it is cloudy before him, together with rain between.

§. 1263. Sometimes two or three bows are seen in the heaven together, concentrick to each other. The internal bow has the most lively colours, and therefore is called *primary*. The external is languid, and therefore is said to be *secondary*. If there is a third, which is but seldom, it appears with very weak and languid colours.

§. 1264. The order of the colours in the two bows is inverted. In the *primary* they will follow in this order, beginning the enumeration from the inward part. Violet, purple, blue, green, yellow, orange, red. The colours of the *secondary* bow succeed one another thus. Red,

orange,

Tab. 26.
Fig. 3.
Tab. 25.
Fig. 9.

orange, yellow, green, blue, purple, violet. Such are the colours likewise that are exhibited by a glass prism, when it refracts the rays of the sun.

§. 1265. That the primary *iris* may be understood, let there be conceived a drop of water BDF, upon which a ray of the sun falls, which is refracted at B to D. From D it is reflected to F, and going out again at F it is refracted in GF, and separated into colours. Tab. 26.
Fig. 1.

§. 1266. On the side towards the sun many parallel rays, such as AA, BB, CC, DD, EE, &c. fall upon the half surface of the drop. Some of these are refracted, and proceeding to the opposite part of the surface baed, go out into the air. Those that do not pass out, but are reflected by the posterior surface bdae, and brought back to the anterior part $\beta\alpha dce$, go out, and are separated from one another to several places. Tab. 26.
Fig. 2.

§. 1267. But there are rays AA, BB, which being near and parallel to one another, fall on the anterior part of the superficies AB, and are refracted to the same point D of the posterior superficies, from whence being reflected forwards to Ff, go out of the drop parallel to one another in FG, fg. These rays being near one another will strongly affect the eye, and therefore are called *effectual*: Whereas others that are too rare cannot sufficiently affect the eye, which is at a notable distance from the drop. Tab. 26.
Fig. 1.

§. 1268. If the ray AA is produced as far as P, and GF be continued backwards to the same point P, and also from the center of the drop C the perpendiculars CL and CM are drawn, as also CA; then CL will be the sine of the angle of incidence, and CM the sine of the angle of refraction, Tab. 26.
Fig. 1.

refraction, which in the red rays are as 108 to 81; and in the violet as 109 to 81. If a calculation is made with these numbers, the magnitude of the arch AE may be found, as also of the arch AD , from whence the angle APG will be $42^{\circ} 2'$ for the red rays, and $40^{\circ} 17'$ for the violet.

Tab. 16.
Fig. 3.

§. 1269. Let a space of the atmosphere XZ be conceived to be full of drops, the spectator in O , and from the center of the sun behind the spectator's back let a line OF pass through the eye O , which is parallel to the rays DE , PS , proceeding to the drops. Of these DE is refracted to K , and thence reflected to n , and going out at this point is parted into colours, and comes to the eye at O in an angle nOF of $42^{\circ} 2'$, where it represents a red colour. In like manner the drop S refracting the ray PS , and sending it to the eye O in an angle QOF of $40^{\circ} 17'$, represents a violet colour. Now let On and QO be imagined to be carried about OF as an axis, and they will describe conical surfaces, whose bases will be circular.

§. 1270. In any visible point of these bases the same colours will be seen under the same angle; wherefore the spectator O will see a coloured arch, having it's latitude nQ of one degree and 45 minutes.

§. 1271. From hence therefore it appears, that according to the different height both of the sun and of the spectator above the horizon, a greater or a less portion of the bow will be seen. For if the sun and the spectator be both in the horizon, OF will be parallel to the horizon, so that the arch which will be seen will be a semicircle. But as the sun ascends above the horizon, OF will be depressed, and therefore the center will be
below

below the horizon, and the lesser portion of the circle will be exposed to view. But when the sun is raised $42^{\circ} 2'$, the right line On will be parallel to the horizon, and therefore the least part of the arch will appear in the horizon; and the sun being raised never so little higher, the whole arch will vanish.

§. 1272. The nearer the rain is to the spectator O , the base of the cone will be a circle of so much the lesser radius, and therefore the bow will appear the less. And the farther off the rain is from the spectator O , so much the greater the base of the cone will be, and the bow the larger.

§. 1273. If the rain falls on the side HC , a part only of a bow HEV will be seen. If on EV , a part of the bow HC will be seen. And if no drops fall from the intermediate part EH , only the legs of a bow EV and HC will be seen.

§. 1274. Because the rain falls from the cloud quite to the earth, a spectator that stands on a plain will see the legs of the bow standing upon the horizon.

§. 1275. If the spectator stands in the middle of a plain, and the rain passes over his head; as it goes forward, and the drops settle in great plenty upon grass and other plants, the legs of the bow will sometimes seem to lye upon a long tract of grass. For the rays of the sun refracted by these drops under the same angles as in §. 1268, will be reflected to the spectator.

§. 1276. And whereas the bow can be seen only under the same angles, it is plain how it will seem to go before a spectator that follows it, and to follow one that goes from it.

§. 1277. The rain-bow is then only conspicuous, when the sky opposite to the sun is cloudy, so that very little light can return from thence. For otherwise this will shine too much with it's own light, and hinder the colours of the bow from being perceived. Therefore the colours of the *iris* will be so much the more intense, as that part of the heaven before the spectator is more opaque.

Tab. 26.
Fig. 4.

§. 1278. Let BDFH be a spherical drop of rain, and AB a ray of the sun, which is refracted at B proceeding to D, from thence is reflected to F, and from F to H, from which point passing out of the drop let the refracted ray be HI, which therefore is twice reflected and twice refracted. Such rays will be *effectual* for forming an *iris*, because their incidence AB and $\alpha\beta$ is near, and after the first reflexion in D and Z they become parallel to one another DF and ZX; and thence reflected to H and S, and a second time refracted in H and S, they proceed near and parallel to one another in HI and SR.

§. 1279. It may be found by calculation, by knowing the ratio of the refractions of the rays out of air into water, what is the angle API in this case. For the red rays the angle is $50^{\circ}, 58', 39''$, and for the violet $54^{\circ}. 7'$.

Tab. 26.
Fig. 3.

§. 1280. If therefore the spectator is in O, and a ray from the sun shining behind drawn through the eye is OF, and the rays darting through the drops of rain AB, PM, being twice refracted and reflected come to the eye O, forming the angle BOF of $54^{\circ}, 7'$, and MOF of $50^{\circ}, 58', 39''$, the violet and red colours will be seen. And the right lines BO, MO, revolving about the axis OF, cones will be generated, in the base of which,

which, under the breadth of 3° , $8'$, $21''$, the coloured bow will be seen, or the secondary *iris*.

§. 1281. The colours of this *iris* are more faint than those of the primary one, because many rays falling between AB and $\alpha\beta$, go out of the drop at DZ ; and part of those which are reflected to XF go out at XF ; so that but few passing out at H and S can arrive at the spectator. Tab. 26.
Fig. 4.

§. 1282. Because the colours of the secondary *iris* are so weak, they cannot be seen, except the sky before be very cloudy; therefore the secondary *iris* is but seldom seen, and the third very rarely. For that this may be seen there must be three reflexions in the drop, and two refractions; besides it is required, that behind the drop the heaven must be quite black, and reflect no light, and the sun must shine very bright behind the spectator's back.

§. 1283. The lunar *iris* is to be explained after the same manner, which, though very rare, yet has been observed by night when it rained, at the time of full moon; but the colours of this are always more faint than those of the solar *iris*; since the moon's light, by reason of it's rarity, has not so much force as that of the sun, with which it affects the drops of rain.

§. 1284. Hitherto we have said the bow was of the same latitude through it's whole extent; and so indeed it is in reality, though it's inferior legs appear to be wider, and it's top narrower: and thence the two concentric bows at their tops seem to have a greater distance than between their legs; which phenomenon depends only on the imagination of the spectator.

§. 1285. Many things might be here added,
relating

relating to the calculation of the angles which the *effectual rays* contain; and other circumstances, which must be omitted in these elements, as being of too subtile and prolix an enquiry. Concerning these and other things relating hereto, the *Philosophical Transactions* should be consulted, N^o. 240, 267, 375; Dr. *Clark's* Notes to *Robault's* Physicks, P. III. C. 17; *Newton's* Opticks and Lectures; *Smith's* Complete System of Opticks, B. II. C. 10; or the Physicks wrote in the *Dutch* tongue.

§. 1286. The sun, moon, planets, and fixed stars, are surrounded by *crowns* or *halo's*. These are luminous circles, sometimes white, at other times coloured as the rainbow. Sometimes there is but one, at other times several concentrical to one another. Those observed about *Syrius* or *Jupiter* have had diameters of 2, 3, 4, or 5 degrees but never greater^a. Those that are sometimes about the moon are small, in diameter 3 or 5 degrees^b: but both these and those about the sun are found to be of different diameters; for they have been observed of 12°, 0'; 22°, 35'; 30°; 38°; 45°; 46°, 24'; 47°; 90°; or greater. Their diameters for the time they continue, are often subject to mutations; also the latitude of the coloured or white rings is different, since they have been of 2, 4, or 7 degrees. When the circles are looked upon with the naked eye they appear oval; and if the diameter is conceived to lie in the meridian, and to be divided into three equal parts, the sun will be two parts distant from the lowest point. When

^a Gassend. ad Diog. p. 584. Marriotte Mouvem. des Eaux. Wolfius in Cogit. ingenios.

^b Newt. Opt. L. 2. P. 4. Obs. 13.

the circles are measured with an instrument they are found to be round ^a.

§. 1287. Whether the circles are coloured or white, the intermediate space between the luminaries and the circles have always a less degree of brightness than the circles themselves. The colours of the *crowns* are more dilute than those of the *rainbow*, and succeed one another in a different order, according to the different amplitude of the *crown*. In those rings observed by *Newton* in the year 1697, reckoning the colours from the inward to the outward, they lay in this order. In the internal *annulus* the blue was within, the white in the middle, and the red without. In the second ring, purple, blue, green, yellow, pale red. In the third, pale blue, and pale red followed each other.

Huygens observed a red colour in the inner ambit, and a pale blue in the exterior. Sometimes I have seen in the inner *annulus* a red colour within, and white without; and at other times the colours were in the same order as *Newton* observed them. *Weidler* took notice of a yellow colour within, and white without.

§. 1288. The cause of these *crowns* is in the atmosphere, not far from the earth. For first, our minds are deceived by making a wrong judgment, and supposing the *crowns* to be about the star itself; which have either no atmospheres, or however not so great ones. Secondly, they are seen but by a few observers at once, and seldom at the distance of two or three miles. Thirdly, they break away when the wind rises. Fourthly, they are not collected but when

^a Smith's Opticks, L. 1. §. 167. R. 344.

the air is stagnant and sluggish. Fifthly, they never appear when the heaven is clear, but when it is covered with a thin cloud. Lastly, when this cloud is driven away by the wind, they break and disperse on that side.

§. 1289. We may imitate this *crown* by art, when in a cold season we make a steam of hot water to arise between our eye and the flame of a candle. Hence it is used to be seen in baths about a light. Also if we re-admit the air into an empty glass receiver, beyond which a candle is placed; for as soon as the air comes to a due degree of density, a *halo* will be seen about the flame with it's several colours^a: wherefore when a *halo* is seen in the heavens, it is produced after the same manner as this artificial one. This may either arise from light passing through the particles of vapour, being twice refracted, or from light running between the interstices of the vapours, and inflected by the attracting forces, and thereby separated into it's colours. The latter cause seems to be the least probable, because of the unequal intervals, which equal globes equally distant leave between one another; so that the equable and continual inflexion of the rays seems hardly to arise from thence. Now light is separated into coloured rings, when it passes through hollow bubbles of water which has been inspissated with soap. And according to the various thickness of the film in the bubbles, a different colour rises, as well by reflexion as passing through. Therefore let there be a thin ball of vapour X,

Tab. 26.
Fig. 5.

and let it's thickness βb be equal to the thickness of the film in a large saponaceous ball, where

^a Boyl. in Cont. Exp. Phys. §. 44.

it forms a red ring by the rays passing through. Let γc be the thickness of a vapour, such as agrees to the yellow ring in the saponaceous ball. Let δd be the thickness in the vapour, such as forms the blue ring in the soap-ball, &c. Therefore in the ball of vapour X the rays $B\beta$ will pass through the annular place βb , and will form a red ring. The rays of the sun $C\gamma$ will pass through γc , which after they have gone out will make a yellow ring; as the rays transmitted through δd will make a blue ring. All these rays will cut the axis $A\alpha a$ at a different angle, tending to the points k, h, g, f, r , continually diverging more and more from one another. But an eye being placed in k, h, g , will see the fore-mentioned colours, and will refer them to different places.

§. 1290. In the plain KX let there be a number of spheres of the same magnitude; a spectator in S , and parallel rays from the sun falling upon them, and likewise let there be formed some coloured rings by the transmitted rays, as in §. 1289. Let RZS be a ray from the sun to the spectator S , and perpendicular to the plain KX , the sun's rays PE falling on that part of the sphere, that passing may form a red ring, and go on to S . The rays PK falling on part of another sphere, so that passing they may form a blue ring, and afterwards be directed to S ; then if ES and KS are supposed to revolve about ZS as an axis, a cone will be generated, in whose circular base the little globes that are situated in the air above, may send to the spectator S blue and red rays, from the rings of the same colour, under the same angle $ESZ, K SZ$: therefore the spectator S will see a coloured circle, red within and blue without. If

Tab. 26,
Fig. 6.

many

many different colours fall within the angle KSE, this middle circle will appear white: But if in KSE are brought the rays of another coloured circle, a circle of that colour will also be seen.

Having thus given the theory of one coloured circle, more may be conceived, furrounding the former. But if the coloured rays coming from several rings of spheres K, E, shall fall upon one another at S, there will only appear a white ring KSE.

§. 1291. If the little spheres KEZ be greater or less at different times, the order of the colours will vary. Hence it is that the same order has not always been observed in the colours of the rings. Also those that give the same colour do not always come to the eye S under the same angle: from whence it follows, that the *crowns* will be seen with different amplitudes: and because the same ball of vapour forms by transmitted rays many different coloured rings, of which in X fig. 5. we have described only four; but their rays cut their axis A and a at different angles; therefore according as these balls are suspended higher up, or nearer to the ground, the rays of different rings will come to the spectator under different angles, and so the *crown* will be seen to increase or decrease in breadth, as has been observed in the same *crown*, that continued for some time.

§. 1292. It is idle to imagine, that these *crowns* are prognosticks of wind, rain, or of a storm at hand. For I have often observed, that a tranquillity followed the next day. More refinements relating to this may be seen in *Newton's Opticks*, l. 2. p. 4. as also in *Huygens's* posthumous works, and in *Smith's Opticks*, B. 2. Ch. 11. *Huygens* has explained very ingeniously,

the nature of these *crowns*, from the hypothesis of hail that is transparent at the outside, but within consists of a dark nucleus of snow. But we have not espoused this opinion, because of the observations §. 1289.

§. 1293. Sometimes in the heaven, together with the true sun, some *mock-suns* have appeared, which are called *parhelii*, because they are seen near the body of the sun, or because they bear some resemblance to the sun itself. Their number varies, for sometimes there are only one or two, sometimes more, even as far as six have been seen.

§. 1294. The magnitude of the *parhelii* is the same as that of the sun itself. The figure is not always round. The brightness is generally more faint than that of the sun, but sometimes as great. If there are many at the same time, some are more dull and pale than others. Their margins, like the rain-bow, are tinged with colours. Many have a long tail stretching from the sun, something of a fiery colour where it adheres to the *mock-sun*; but at a greater distance it becomes paler. And some are without a tail. The tail is extended in a white horizontal circle.

§. 1295. The *parhelii* are almost always attended by certain circles, of which some have the colours of the *iris*, and others are white. They are also variable in number and magnitude; yet all have the same latitude equal to the apparent diameter of the sun. There are some circles which surround the sun placed in their center. These are coloured, and have a diameter of 45 degrees, nay some have been observed as large as 90. The plain of these is Tab. 26. perpendicular to a right line drawn from the Fig. 10. spectator through the center of the sun; therefore

fore their situation is different according to the different elevation of the sun above the horizon; the more lively their colours appear, so much the more languid is the light of the sun. There are other circles, which are parallel to the horizon, of which commonly one is larger than the rest, is white, and comprehends all the *parbelii*, and which if intire would pass through the real sun: the center of this is the zenith. *Hevelius* saw one of these, whose diameter was 130 degrees. Sometimes there have been arches of lesser circles concentrick to these; which as they passed over the former coloured ones, covering them only by their breadth, were also tinged with colours, and were in a plain passing through the zenith and the sun, and contained the other *parbelii*. There were also other circles situated obliquely in respect of all those beforementioned. The order of the colours in the tinged circles was the same as in the *iris*; but in the inward part next the sun is the red colour, as is also observed in many of the *crowns*.

§. 1296. *Parbelii* have been seen for the space of one, two, three, or four hours, when the sun was elevated at different altitudes; then the *parbelii* vanish, then the circles by degrees, first on one side, and then on the other, often seeming to return in those places, where they began first to vanish, till at last they quite disappear.

§. 1297. The matter of the *parbelii* has likewise it's abode in the earth's atmosphere. First, because the coloured circles that encompass them are only *crowns*, the matter of which, by §. 1288, is suspended in our air. Secondly, according to the accurate observations of *Hevelius*, *Huygens*, *Cassini*, *Maraldus*, *Verdriesius*, and my own, at
the

the time of the *parbelii* the heaven was never perfectly serene, but covered with a thin transparent mist. Thirdly, the more lively the colours of the circles are, so much the more the light of the real sun is pale and faint. Fourthly, they are hardly seen in two places at the same time, though those places are but little distant from one another; for the *parbelii* seen at *Harlem*, February 22, 1734, did not appear at all at *Utrecht*. So two remarkable *mock-moons* with their crowns, were seen March 12, 1734. in the villages of *Catwick* and *Koudekerk*, as also at *Leyden*. Nor was any thing of this seen at *Utrecht*. Fifthly, they are generally observed in the winter-time, when it is cold, with a moderate frost, a mild wind blowing, either from the north or pretty near it. Lastly, when the *parbelii* are over, sometimes rain follows, and sometimes snow, which consists of oblique spikes or flakes.

§. 1298. Because the *parbelii* do not always appear with the same phenomena, their causes may indeed be similar to one another, but not exactly the same; therefore in the theory which we shall give of one observation, something must be changed, whenever there shall be other circumstances in other *parbelii*.

§. 1299. Let us suppose *spicula* of ice, very fine and cylindrical, to be suspended aloft in the air, such as sometimes fall down under the form of snow; and let these begin to melt by the beams of the sun, so as that the middle dark nucleus CD may not yet be melted, but the external parts AB, AB, melting only may be transparent; and let part of the melted water dropping downwards form a little globe BEB. Such a *spiculum* will swim erect in the air, because of the situation

Tab. 26.
Fig. 7.

of it's center of gravity between D and E. These things supposed, it will not be difficult to explain the phenomena of the *parhelii*, as I shall shew in these observations. Nor are these precarious positions; for first, there are actually such cylindrical *spicula* sometimes in the air. Secondly, at the time of the *parhelii* they have been observed to fall. And thirdly, such as these made by art, of glass, and full of water, with a dark piece of wood in the middle, being suspended on high, have exhibited the phenomena of the *parhelii*, as *Huygens* the author of the solution has observed.

Tab. 26.
Fig. 8, 10.

Tab. 26.
Fig. 7.

§. 1300. Since these *spicula* hanging in the air must intercept some part of the sun's light, he will be less resplendent than in the serene heaven. Let *SR* be the sun, and let *SP*, *RQ*, be supposed to be rays emitted from the extremities of his diameter, which falling upon the surface *AB*, may be supposed to fall only upon a line, and therefore have their incidence as it were upon a plain speculum, from which being reflected under equal angles, they will proceed in *PV*, *QV*. A spectator placed at *V* will receive this light, which will be weak; for only a small line *QP* is the reflecting body. The rest of the light falling on the side of this upon the other part of the superficies will be reflected a different way in respect of *V*. Now the shining object in *V* will appear in this speculum *PQ* at the same altitude above the horizon, as the sun *SR*, and under the same longitude with *SR*, by §. 1038; but not under an equal latitude, because *PQ* is only a reflecting line.

Tab. 26.
Fig. 7, 8.
10.

§. 1301. If therefore the spectator was in α , and his zenith at β , and if the angles $\lambda \alpha \beta$, $\xi \alpha \beta$ are equal to the angles ZVP , ZVQ , of fig. 7, because of the rays reflected on all sides by the *spicula*,

spicula, a white ring $\kappa\lambda\mu\nu$ will appear to him at α , of the same elevation above the horizon as the sun γ , and of equal breadth to his diameter.

§. 1302. The sun also darts his rays SP , RQ , which entering into the transparent cortex of the *spiculum*, are refracted at PT , QX , in this icy substance. But going out again at TX , are carried through the air in the right lines TY , XY , parallel to the former SP , RQ ; and because the thickness PT is very small, a spectator placed at Y will judge these rays to proceed from an object placed no higher than RS . Not only the rays falling upon the line PQ will arrive at the spectator placed in Y , but others also of the neighbouring lines. And since all are refracted at going out of TX and the neighbouring surface, they will be separated into their colours, most of which falling upon one another will exhibit their former whiteness by §. 931. Others that come near to the sides, will be seen under their own colours. Tab. 26.
Fig. 7.

§. 1303. If we conceive these *spicula* in the white circle which I just now explained in §. 1301, it is plain that to a spectator placed in α , many such rays will be transmitted by the *spicula*, which are situated between him and the sun γ , and there will be a certain place, in which the *spicula* will send the refracted light to the spectator in the greatest plenty. This is the occasion, that a mock-sun will appear in the white circle at ν and κ . And since the neighbouring *spicula* always transmit so much the less light passing in this manner to the place α , as they are more remote from the sun γ ; therefore a shining tail will seem to adhere to the *parhel* ν and κ , but included in the white circle. And because of the lateral rays that are refracted into

colours, the *parbelii* and the tails will be seen with coloured limbs, and the tails will be less refulgent at their latter parts, and stretched out the fourth part of a circle from the sun γ .

Tab. 26.
Fig. 9.

§. 1304. If the rays of the sun OM are propagated in the plain AB , they that would have proceeded directly to K , being refracted will be carried in the *spiculum*, and it's plain BC to P . But being reflected by it's farther point P , they will move in the plain CD to G , where going out of the *spiculum* and being refracted from D to F , they proceed in the plain ED . Being carried in these plains, and drawing HF parallel to the side of the *spiculum* DG , they will come to F , under the same angle HFG as if they had been directly reflected from the point K , and therefore under the same angle as that of their incidence on the *spiculum*.

Tab. 26.
Fig. 10.

§. 1305. Again let the *spicula* be conceived in the white circle; the rays emitted from the sun γ , and twice refracted and once reflected at the *spicula* λ and μ , will come to a spectator at α under the angle $\lambda\alpha\epsilon$, and in a good quantity. Wherefore here again *parbelii* will appear at λ and μ , though not so bright as the former; because though many rays are reflected by the hinder part of the *spicula*, yet many pass out likewise. Therefore their tails will be so weak as not easily to be discerned.

Tab. 26.
Fig. 7.

§. 1306. A little spherical drop BEB adheres to the lower part of the *spicula*, through which light passing forms the coloured rings FG , HK , LM , as we have seen in those globes that produce the *halo's*, §. 1289. Therefore these will exhibit like rings to view, tinged with the colours of the *iris*, $\delta\epsilon$, $\eta\kappa$, $\nu\theta$, Fig. 8. which will encompass the sun γ , and will be either
single

single ones or several, situated in another plain perpendicular to a right line, drawn between the center of the sun and the eye of the spectator.

§. 1307. If the motion of the air will not suffer these *spicula* to be at rest, but should move them a little towards one side, and weaken them; the brightness of the *parhelii* will immediately be changed. So that they will seem to be in a state of continual labour. He that desires more and more curious speculations about this subject, may consult the dissertation of the great *Huygens* concerning *crowns* and *parhelii*; as also Dr. *Smith's* Opticks, B. II. C. XI.

§. 1308. *Paraselenæ* also appear about the moon, with like tails and coloured circles, as now mentioned in the *parhelii*. Their cause without doubt is analogous to that of the *parhelii*, and their phenomena may be explained in the same manner.

§. 1309. Sometimes the sun seems to emit from the clouds *luminous streams*, or *virgæ*, extended as far as the earth, in the form of cones, being widest near the earth. They are generally seen in the afternoon, after hot weather. They shew themselves when the clouds deprive the spectator of the sun, when the thin and distant rays are directed towards the earth, through the narrow interstices of other clouds. These rays meet with the ascending vapours, and being viewed laterally affect the sight strongly. As when the beams of the sun are admitted into a close place, we see little corpuscles floating about, some moving upwards, some downwards, and meeting one another in all directions. But when these rays are viewed sideways, which are thus reflected by the corpuscles, they appear in the

form of the *virgæ* or luminous streams above described.

C H A P. XL.

Of fiery Meteors.

§. 1310. **H**A V I N G now dispatched the principal watry meteors, we must proceed to the fiery meteors. But here we must take great care, that we do not confound those that are only shining but not fiery, with such as actually burn. For there are some shining, as the *parbelii*, and the *halo's*, which strike the eye more strongly than those that are fiery. Even the clouds sometimes reflect the light of the moon more forcibly, and seem more to burn, than some *auroræ boreales*. Likewise we must take care that we do not confound the morning and evening twi-light with these meteors, as also the luminous tracts of the milky way, or the light of the zodiack observed by *Cassini*, and excellently described by *Mairan*.

§. 1311. Fiery *meteors* either emit a faint light, and are rather shining; or they dart out a bright light, and burn. To the first belong the *auroræ boreales*, with all their various species; to the latter belong thunder, lightning, and such like. Let us first examine the nature of those that shine.

§. 1312. Antiquity has affixed various names to these luminaries, agreeably to their figure, to which they have given more attention than to search out their cause. Though they may all consist of a like matter, yet this may be notably distinguished by the quantity of different earthy exhalations, which being set on fire may shine.

It is called *trabs*, or a *beam*, when an oblong light shall appear, parallel to the horizon. An *arrow*, or *sagitta*, has the figure of a beam, but only it terminates in a point. A *fax*, or *torch*, has it's light placed in any situation, but has a broad extremity. *Capra saltans*, or the *dancing goat*, was that light, which by the force of the wind was changed into various shapes, is sometimes interrupted, and sometimes appears whole again. *Boethynoe* is that, when a great tract of the heavens within is encompassed as it were with a crown, like a cave sunk in a circular manner. *Pitbia* is when a light moves or seems to burn, like a vast round barrel.

§. 1313. As the *auroræ boreales*, by reason of their frequency in this last age, have begun to be better known, I had a suspicion that the lights mentioned in §. 1312, might be of the same kind. For I have sometimes observed clouds in the heavens, shining with a mild lustre, and of different forms, to which the ancient names agreed very well. But these must be referred to the *auroræ*: As first, I seemed to gather from their light. Secondly, because they were seen in the north, or came that way. Thirdly, because some of them, after they had shined agreeably, began to send out columns from themselves, as the *auroræ* are used to do. Such clouds are not easily distinguished from the rest, unless any one is well accustomed to the observation of *auroræ boreales*, and takes notice whether they are not illuminated by the sun, or by the moon. Therefore *auroræ boreales* may be divided into two species, into those that are mild, or flashing. To those that are mild may be referred the meteors mentioned before in §. 1312. As also that *aurora* which was seen in *France*, *October 9, 1730.* by Mess.

Cassini and *Mairan*. This was extended horizontally from north to south, without columns or shootings; and breaking in the middle went away in two oval lights ^a.

§. 1314. The flashing *aurora borealis* constitutes the other species. This is that which is vulgarly called the *northern lights*. It is no new meteor, but known even from the most ancient times; described by *Aristotle* ^b, *Pliny* ^c, *Seneca* ^d, and others after them. *Frobesius* has wrote the best catalogue of them ^e. But they are not so frequent in the more cultivated parts of *Europe* remote from the north pole. After the year 1716 they began to appear frequently in *Holland*. And though they are very common in the northern parts, yet it is plain from the observations of *Burman* and *Celsius*, that the brighter *auroræ* were formerly but rarely seen in *Sweden*; and this astronomer being desirous to observe them after the year 1716, from that time collected above three hundred and sixteen that appeared there ^f. They are very often seen in *England* and *Germany*, seldom in *France*, and very rarely in *Italy*. For before the year 1722 hardly any appeared there; and from that time only twice or thrice at *Bononia*. So that in *Italy* this phenomenon is accounted a very rare one, as the *Bononian* commentaries testify ^g, since the *aurora* of the year 1727 was the first, which in *Italy* in the memory of man fell under the ob-

^a L'Hist. de l'Acad. Royal. An. 1730.

^b Meteorolog. l. 1. c. 4, 5.

^c Hist. Nat. l. 2. c. 26.

^d Quæst. Nat. l. 1. c. 15.

^e Nova & Antiqua Auroræ Borealis Spectacula.

^f Observationes de Lumine Boreali.

^g Comment. Bonon. p. 285.

servation of any astronomer. Wherefore *Polenus*, *Bosellinus*, *Baldinus*, and *Zanottus*, observed and described the *aurora* of the year 1737 with a great degree of accuracy and diligence^a.

§. 1315. Not always the same appearances, but very different ones, accompany the *aurora borealis*: But generally they are in this manner. In the northern coast of heaven, either due north, or thence to the east, or on the other side towards the west, a cloud appears, which either lies in the horizon, or is elevated above it a few degrees, seldom so high as 40, yet is sometimes extended as high as that. Or the cloud is separated from the horizon, so that the blue sky may be seen between it and the horizon. As to length it possesses various parts of the horizon, from 5 or 6 degrees as far as a 100 or more. This cloud is white, not very bright, oftener thick and dark. It's upper limb is parallel to the horizon; yet sometimes it is gibbous, like a bow, so that it is like a round dish a little above the horizon. Sometimes to the upper margin of the black cloud there adheres a broad limb, that is concentric, white, or brighter. Even to the lower margin of the black cloud a lucid limb has been observed to adhere, unless both the bright limbs belonged to two black clouds distant from one another, one of which was higher above the horizon than the other, as seems to be gathered from other observations^b. Sometimes the black part has been converted into a white shining cloud, after the *aurora* has shined for some time, and thrown out many flashing streams. But it has been observed like-

^a Poleni sopra l'Aurore Boreale.

^b Miscellan. Berolin. T. I. p. 132.

wife, to have returned to it's former opacity. The heaven shines brighter above the upper limb of the cloud, but this brightness is presently changed, being sometimes increased and sometimes diminished.

§. 1316. From the upper limb are emitted streams of light, either more or less, near one another, or a few degrees distant, which are very bright and shining. Just as if some shining liquor was squirted out of a fountain with the utmost violence. It is a jet of fire something bright and fuming. Yet where it goes out of the limb it is most shining and contracted; it becomes rarer and less shining and broader, the farther it proceeds. A matter that is less shining, and like smoke, follows the brightness out of the same place of the limb. This is soon after followed by a brighter, as if water were squirted out of a pipe of a fountain, with which now and then some air was interspersed, which interrupted the equable shooting of the water. This luminous matter is exploded with the most rapid velocity. Sometimes a lucid column arises out of a wider aperture, slowly, with an equable motion, wider as it proceeds, continuous, not leaving the limb of the cloud. This continues for 10 or 20 seconds or more, and I have seen some continue for 4 or 5 minutes; but this is not usual, as likewise those streams which adhere to the cloud with a wider base, and mount upwards with a sharp point. There are also columns, which as soon as they have departed out of the limb are not seen, till after they have advanced a good way. These do not adhere to the limb, but seem to be produced from the serene air. Some columns stand perpendicular to the horizon, others are oblique, others are arch-ways, others

are

are brandished as it were from the center of an orbicular cloud. They are of different lengths, sometimes rising only to 4 or 5 degrees from the brink of the cloud. If they shoot out with rapidity, they mount even to the zenith of the observer. If they are exploded with the utmost rapidity, they go beyond the zenith, nay, even to the southern horizon. They do not always ascend to the zenith directly out of the cloud, but they are inclined side-ways, especially if an illuminated cloud is suspended in the middle between the north and the east, or west. The place was observed by *Kircher* at which the columns concurred, which declined 29 degrees from the zenith towards the south. The lucid columns contain a white light, reddish, or blood-colour. When they advance farther the colour sometimes changes in their course, so as to resemble the iris. When several that are emitted from different coasts of the limb meet one another in the zenith, they mingle together, the parts penetrating one another, or dividing, involving one another in every direction. Then they form a pretty thick cloud or mist, which presently taking fire on all sides, burn more furiously than before, and spread a light which is green, or blue, or purple. This immediately leaving it's place under the form of a bright cloud, betakes itself to the southern coast of heaven. It has also been observed by Dr. *Halley*^a, and *Mairan*^b, to be permanent for some time, and to assume the form of a spherical vault perforated in the middle. Sometimes new columns soon follow those that went before, and which vanished away;

^a Philof. Transf. N. 347.

^b L'Hist. de l'Acad. Royal. An. 1726.

sometimes

sometimes it desists for some minutes, as if the nourishment failed, before it produced new ones. The lucid columns are so thin, that stars of the first and second magnitude shine through them. These may often be seen likewise through the white limb of the cloud; nay, they have been seen through the black cloud, though this but seldom. The columns often vanish or are dissipated in the sky, as it were insensibly, so that it continues to be clear towards the south. Yet sometimes in those places, where the columns seem to have ceased, others break forth unexpectedly. Sometimes they go off in little clouds, which are carried away from north to south; therefore after the meteor has continued for some time, a great part of the sky is filled with thin clouds.

§. 1317. Sometimes from a cloud, the source of this light, a very thin shining matter is exploded with great rapidity, though not to obscure even stars of the sixth magnitude. This matter is sometimes shining, sometimes extinct, as it were by equal fits, or as if it were propagated like waves, that shined in descending, and opaque as they ascend. Is not this the *capra saltans* of the ancients? I have seen this moving in a very broad tract, with a strait direction, and carried far beyond the zenith. I have seen also little lucid clouds broke off from the limb of a shining cloud, carried from north to south, without any streams of light.

§. 1318. The flashing columns do not always seem to be propagated from a cloud; for it sometimes happens, that the whole horizon seems shining with very bright light, and that out of this light every now and then short lucid columns are projected. Perhaps then the cloud, which is
the

the source of the light, is suspended a little below the horizon, or is so small and thin, that it cannot be perceived by the eye.

§. 1319. This meteor sometimes continues for a whole night, nay it frequently appears for two, three, or more nights successively. There are also *auroræ* of but a few minutes continuance.

§. 1320. It is observed to appear sometimes in one place, when in the neighbourhood, at but few miles distance, it is not seen at all. Sometimes there is so great a quantity of it, that at the same time it may be seen almost over all *Europe*; as was the *aurora borealis* of the year 1716, *March* 17. And that of 1726, *October* 19. Also that of 1729, *November* 16; which is very elegantly described by the learned *Weidler*^a. Yet in different countries it is to be seen with very different circumstances.

§. 1321. The cloud which is the source of the *aurora borealis* very often continues unchanged for many hours, nor does it ascend higher above the horizon, or descend lower. Yet sometimes it moves a little from the north towards the east or west. Nay sometimes it dilates itself both ways, and then emits several columns from every part. It has also been observed to ascend above the horizon, and to be converted into a white shining cloud. But in *Lapland* and *Moscovy* this *aurora* is seen with other phenomena, and possesses as well the southern quarter of the heaven as the northern; as the most industrious Mr. *de Maupertuis* has observed^b, as likewise Mr. *Delisle*^c.

^a Commentario de Aurora Boreali.

^b Figure de la Terre.

^c Memoires pour servir, &c.

§. 1322. This *aurora* has been observed when the sky was every where serene and blue, excepting towards the north, or only here and there with some clouds. I never saw an *aurora* when the heaven was quite covered with clouds; but after it had shined out, in a short time clouds covered the whole sky. It appears also when the wind is quite still, or only makes it's first impetus. It is less frequent when the second impetus blows, and seldom or never when it blows a storm. Yet I saw it *March* 30, 1728, and *December* 23, 1733, when the wind was of the fourth degree, which I reckon the most rapid. I have observed *auroras* to shine when the wind blew from every quarter. And they have been seen at *Utrecht* at all seasons of the year.

§. 1323. Likewise all kinds of winds, mild and vehement, have preceded these *auroras* indifferently. Cold and hot seasons, moist and dry. So that we can make no presage from hence of their coming. The seasons also that followed have been fair and rainy, the winds of all kinds, mild and strong; heat and cold; for they bring no certain change to the atmosphere, nor any diseases, nor are they any cause of a hard winter, since very mild ones have followed them. Nor do they forbode any dire calamities, as *Bosselline* has judiciously proved.

§. 1324. That the *aurora borealis* is within the earth's atmosphere may be hence proved. First, because it appears in the form of a cloud, which is like the other clouds of the atmosphere. Secondly, because the flashing cloud often continues at the same height above the horizon for the space of many hours, nay days, and therefore revolves about the earth's axis together with the earth and the rest of the atmosphere. And lastly,

because

because the *aurora* is not often seen at the same time in two different places, though those places are not far asunder.

§. 1325. How high it is above the surface of the earth no one as yet has been able to determine; though very good mathematicians have begun to deliver rules for that purpose^a. For it is not certain that it is the same light, or in the same place; particularly that that shone over all *Europe*, and was observed in the years 1716, 1726, 1729; so that from the height of the flashing cloud, observed at different places, the parallax may be securely determined, and thence the elevation.

§. 1326. The matter of the *aurora* is of such a nature, as to be set on fire, and when inflamed can shine with a faint light, and continue to be rare: For the stars may be seen through it. But who can pretend to assign it's nature and properties, without great rashness? Chemistry supplies us with specimens of inflammable and phosphorean matter, that are almost innumerable^b; and nature has shut up in the bowels of the earth many others of different kinds, which art has not yet arrived at. This matter seems to expire out of the northern quarter of the earth, more plentifully now than before the year 1716; because it's nutriment may have found it's way by means of an earthquake. And this being consumed, these *auroræ* will cease perhaps for many ages. This perspired matter ascends on high, composing one or more clouds, which are carried over various

^a Comment. Petropol. T. I. p. 365. L'Hist. de l'Acad. Roy. An. 1731.

^b L'Hist. de l'Acad. R. A. 1711, 14, 15, 28, 36. Hooke's Phil. Exp. p. 174.

regions,

regions, nor is it inflamed till it meets with other matter, from whence arises a hot and ignivomous effervescence, of which kind many have been discovered by art in our times. If therefore a cloud consisting of the matter of the *aurora* be carried by means of a northerly wind, from the north, which is as it were it's native country, to other distant regions, where it meets with exhalations dispersed through the air with which it can raise an effervescence, it will be inflamed in that part where it meets the exhalations, that is in the southern part. So that by a spectator placed to the south it will be seen to burn, and in respect of him the light will be in the northern coast, and the phenomenon to the north of him. And because exhalations are not inflamed till they are something mingled with one another, and the cloud on the northern side being extended in a long tract, gives more resistance than on the southern side, in the superficies of which, at least in it's anterior part, the permission happened, the explosion of the effervescent and inflamed matter will be on this side, and therefore from north to south with various directions, now upward perpendicularly, now parallel to the horizon, now below parallelism. Hence from the matter bursting forth, and making way for itself, columns or lucid streams will shew themselves, having a various situation in respect to the horizon, with directions towards the zenith of the spectator. And as exhalations of another kind shall mingle with the effervescent ones, the colour of the streams will be different. Now they will exhibit white light, now that of a rosy colour, now red, now yellowish. And may not an auroriferous cloud continue immoveable for some time, in respect of the horizon, if it be

urged with equal force from north towards the south, as that with which the airy exhalations, by means of a southerly wind are drove towards it? Many of it's phenomena seem thus to be easily explicable, from sources which perhaps will not be far from the truth. That excellent mathematician *Mairan* has very well explained in his most elaborate work many other things relating to the *aurora*. But they that have recourse only to sulphur and nitre, as the causes of *aurora*, do not seem sufficiently to attend to the very different inflammable matters with which the atmosphere is replenished. These when inflamed excite phenomena that are different from those of sulphur; for the flame of this differs very much from the light of the *aurora*. Again, why should not the *aurora* be as frequent towards the south, as now they happen towards the north, since *Italy* and the southern countries, as also the burning mountains, expire much sulphur? But hitherto in *Holland*, *Germany*, and *France*, very few *aurora* have been seen towards the south, and much fewer in *Lapland* and *Muscovy*. Yet they appeared in the years 1704^a, 1734^b, and 1741. It will be better to attend diligently to the *aurora*; for perhaps the matter itself, at some time or other falling from the sky, may afford an opportunity of examination, or art may prepare something like it, by which it may be known; or it's native place may be discovered in the superficies of the earth. The lake *Weter* in *Sweden* sends forth a matter not much unlike it^c.

^a L'Hist. de l'Acad. Royal. A. 1705.

^b Weidler. de Meteor. lucid. sing.

^c Philos. Transf. No. 298.

§. 1327. A small fiery ball, shining with a bright light, is often seen to move through the atmosphere in a clear sky, nay and to fall down upon the earth. As this in it's apparent magnitude seems to resemble a star, it is called a *falling star*, or a *shooting star*. It is generally observed in spring and autumn, and only by night, because in the day-time it is obscured by the greater light of the day. For it is very probable, that there are not fewer that fall by day than by night^a. When the place is found where it fell, the matter that remains is stiff and clammy, white inclining to yellow, marked with small black spots, and has lost all it's inflammable substance, as *Fludd* and *Brusseus* have taken notice^b. This fire runs through those tracts of the atmosphere, in which the inflammable matter floats and adheres. This kind of stars may be imitated by art, if we make up in form of a ball camphire with nitre and earthy mud, macerated with wine or it's spirit. This ball set on fire, and thrown up into the air, will perfectly resemble a falling star, with a like remaining tenacious dreg. Such productions as these, and other like inflammable substances, are to be found in the atmosphere.

§. 1328. Certain small flames, which in a tempest at sea adhere to the masts, ropes, or other extant parts of ships, are called *Castor* and *Pollux*. Sometimes one, two, or more are observed together. Sailors tell us, they are little shining fishes, which are tossed up by the waves with the foam of the sea, and adhere to all the prominent parts of the ship, which there shine as long as they continue alive. It is a mere fable that one of them alone is

^a Gassend. Phys. §. 3. 1. 3. c. 7.

^b Gassend. 1. c.

a bad omen, but that two of these little flames are good signs, and denote that the storm will soon cease ^a.

§. 1329. *Wandering fires*, or *ignes fatui*, are of a round figure, in bigness like the flame of a candle, but sometimes broader, and like bundles of twigs set on fire. They sometimes give a brighter light than that of a wax candle, at other times more obscure, and of a purple colour. When viewed near at hand they shine less than at a distance. They wander about in the air, not far from the surface of the earth, and are more frequent in places that are unctuous, muddy, marshy, and abounding with reeds. They haunt burying places, places of execution, dunghills. They commonly appear in summer, and at the beginning of autumn. But in the country about *Bononia* they are seen throughout the whole year in a dark night. For there in a cold winter, and when the ground is covered with snow, they are in greater plenty than in the hottest summer. Those also are observed in winter, which *Gassendus* says are seen at *Rogon*, a town of *Provence* ^b. They appear more frequently in hot than in cold countries. In *Italy* near *Bononia* are the greatest and in greatest plenty ^c. Sometimes they vanish on a sudden, and presently shine out in another place. They are generally at the height of about six feet from the ground. Now they dilate themselves, and now contract. Now they go on like waves, and rain as it were sparks of fire, but they burn nothing. They follow those that run away, and fly from those that follow them. Some that have been caught were observed to

^a Plin. Nat. Hist. l. 2. c. 37. Cardan. de Subtil. l. 2. p. 69.

^b Physic. l. 2. §. 3. c. 7.

^c Philos. Trans. N. 411.

consist of a shining, viscous, and gelatinous matter, like the spawn of frogs, not hot or burning, but only shining; so that the matter seems to be phosphorous, prepared and raised from putrified plants or carcases by the heat of the sun; which is condensed by the cold of the evening, and then shines. Yet I do not think that the matter of all is the same, for without doubt those of *Bononia* differ from those of *Holland*. It is a mere fiction that these fires are evil spirits, or wandering ghosts, misleading travellers out of mere spite, to plunge them into ditches and bogs, as some trifling Philosophers have told us.

Hither is to be referred another kind of wandering fires, which I call *incendiaries*, because they not only shine like the former, but also burn, and set fire to stubble, straw, thatch, and houses themselves, such as were formerly in *Germany*^a, and in our time in *Switzerland*^b, and in *Italy*^c. These sometimes were of a round figure, and of a disk like the moon, sometimes like a rope, and now like a small fickle; some stand still, others move with any direction, sometimes slow and sometimes quick, but not swifter than a man can run. They were observed by the ingenious *Ripa* in the *Trevisan*, and are well described by him.

§. 1330. That is called a *lambent fire*, which sometimes has been seen to adhere to the hairs of children^d, and adult persons^e, and to the manes of horses; especially when their manes are combed. These fires are nothing else but a real phosphorus, such as art prepares from the parts

^a Tacit. l. 13. Annal.

^b Kaschubii Elem. Phys.

^c Ripa Differt. Meteor.

^d Livius, l. 1. cap. 39. Virgil. Æneid. l. 2.

^e Cardan. l. 8. c. 43. Variet. Act. Phys. Med. V. 3. O. 3.

of animals. This expiring from the body together with the sweat, adheres to the hair, the forehead, and other parts of the body; and is inflamed by rubbing the hair, as is done by combing it. And hence also the foul linen of sweaty workmen will shine by rubbing. It is also said to adhere to the iron point of a spear, when anointed with unctuous matter ^a, or to darts ^b; but perhaps this is different from the former. It is only a small wandering flame, which being allured by the oily matter with which the spear has been anointed, applies itself to the spear, rather than pass by it in the open air.

§. 1331. Sometimes by night vast luminous tracts appear in the air, and are suddenly removed from one place to another, which an ignorant person would imagine to be a meteor. But this arises only from flies, which flying by companies in the night-time, expire a phosphorean light from all parts of their bodies; as has been observed by *Scheuchzer* in *Italy*, and is also confirmed by *Willoughby* and *Ray*.

§. 1332. To the brighter meteors belong a *bolis*, *thunder*, and *lightning*.

We call a *bolis* a great fiery ball, swiftly hurried through the air, and generally drawing a tail after it. *Aristotle* calls it *capra*. There have often been immense balls of this kind; for the ancients tell us there have appeared some as big as the moon ^c. *Gassendus* himself saw one, whose diameter was as big again as that of the moon ^d. This meteor he calls *fax*. In the year 1686, at

^a Senec. Q. N. l. 1. c. 1.

^b Plin. l. 2. c. 37.

^c Seneca, Q. N. l. 1. c. 1.

^d Phys. f. 3. l. 2. c. 7.

Leipsick, *Kirchius* saw such a *bolis*, whose diameter almost equalled the moon's femidiameter, which illuminated the earth so strongly by night, that a man might read by it without a candle, and it vanished by degrees. It was also seen in the town of *Schleis*, eleven German miles from *Leipsick*. Hence it may be concluded, that this ball had an elevation of six of our miles at least. If the length of a mile be 12000 feet, the diameter of this burning ball will be 335 feet; but according to the calculation of others it was as big again. The *bolis* observed at *Bononia* in the year 1719 by *Balbus* was much larger^a. It's diameter seemed to equal that of the full moon, and was of a colour of burning camphire. It diffused a light around it as great as the sun is used to do at his rising, so that the smallest things upon the ground might easily be seen. There appeared in it four gulfs casting out smoke, and many little burning flames upon the ball, which were emitted from it. It had a tail seven times as large as the ball itself. It appeared from comparing the altitudes which the ball seemed to have in different places, that it was elevated above the surface of the earth not less than 16000 nor more than 20000 paces, and therefore it's diameter was equal to 3560 feet. It scattered a strong smell of sulphur in those places it passed over, and burst with no small noise.

§. 1333. It sometimes happens, that at the vanishing of this kind of balls a little cloud of an ash-colour remains behind in the air^b. Some advance forwards, some seem to stand still for a time

^a Comment. Bonon. p. 285.

^b Whiston of the Meteor, An. 1719.

in the same place of the atmosphere, as those observed by *Kirchius*^a and *Wolfius*^b; yet all these shined so clear, as much to exceed the light of the moon in their brightness.

§. 1334. Because in those places they pass over, they leave the smell of sulphur behind them, we make no doubt but that a *bolis* is a cloud consisting chiefly of sulphureous and other inflammable exhalations set on fire by the effervescence raised by meeting with other exhalations. The fluid matter when on fire in the fluid air takes the figure of a globe. Some balls have been observed to rest, when the inflammable exhalations have not been drove out of their place of tranquillity, where they were suspended; or when they have took their rise at a distance from the spectator, and urged towards him, it could not be discerned, whether they stood still or moved. Also other balls have been observed to be carried with a very rapid velocity, which might be on two accounts. First, because inflammable matter was suspended in that whole tract of air, through which the *bolis* passed, which matter took fire successively. As in a long train of gun-powder, the flame runs from one extreme to the other. Therefore the ashes that remain after the fire resemble a pale ash-coloured tail, in the whole course described by the *bolis*. Or secondly, because the burning sulphureous cloud, every way expanding itself, was opposed by the resistance of other exhalations floating in the air, with which by effervescence it took fire. Yet the first cause seems to me the

^a Ephemer. German. Cur. An. 1688.

^b Acta Lipsica, An. 1708. p. 526.

more probable, because these balls run over different countries for a vast length. The brightness of the light proves, that the burning matter is very solid, so as to collect a great quantity of fire; such is that of sulphur, of the oils from vegetables, with other earthly mixtures, perhaps with salts. For the white colour of the flame evidently shews, that it is not pure sulphur that burns.

§. 1335. The great light observed by *Montanarius*, in the year 1676, was probably a kind of *bolis*. This Mathematician was then at *Bononia*, and it appeared to him as coming out of *Dalmatia* over the *Adriatick* sea; a crackling noise was heard in those places over which it was vertical. Moreover at *Leghorn* a sound was heard like the shooting of guns; and after it had passed towards the *Corfican* sea, a noise followed like the rattling of coaches over stone pavements. This light moved very swiftly, no less than 160 *Italian* miles in a minute.

§. 1336. *Lightning* is a great flame, very bright, extending every way to a great distance, suddenly darting upwards, and there ending, so that it is only momentaneous.

§. 1337. It lightens as well when the sky is clear, as when it is cloudy. Lightning very seldom happens but when some hot days have gone before. It lightens without thunder, yet generally this attends it. At *Utrecht* it hardly lightens three or four times a year, but there is thunder along with it. It seldom does any damage to things upon the earth, because this fire is high in the air, to which place it is commonly confined.

§. 1338. The matter which produces the fire, is the oil of plants, attenuated by the heat of the day and raised on high. Then whatever has exhaled

haled from the earth that is sulphureous or oily, which is dispersed up and down in the atmosphere, and is not continuous, is set on fire by turns, and the flame dilates itself as far as the tract of that exhalation reaches. Some other substance pendent and floating in the air meets with this also, with which it excites an effervescence, takes fire, and flashes along with it.

§. 1339. *Thunder* is a most bright flame, rising on a sudden, moving with great violence and with a very rapid velocity through the air according to any determination, upwards from the earth, horizontally, obliquely, downwards, in a right line, or in several right lines, as it were in serpentine tracts, joined at various angles, and commonly ending with a loud noise or ratling.

§. 1340. It appears from observations taken at *Utrecht*, that every year it thunders there fifty times, taking them at a medium. It thunders oftenest, and a like number of times, in the months of *May* and *July*, and three times oftner in these months than in *April* or *September*; and as often again as in *June* or *August*; for it thunders an equal number of times in *April* and *September*, and as often in *June* as in *August*. It seldom thunders at any other time of the year but in the aforementioned months. It proceeds also from any quarter, the winds either then blowing or having blown before. Most frequently when the south wind blows, but less the east wind blowing. With the same frequency, though something less, when the south-east or west winds prevail; most seldom of all when the north-east, the north, or north-west winds blow. But these circumstances are peculiar to that city and the neighbouring country; for in other places different Observations obtain.

§. 1341.

§. 1341. Because places that have been thunder-struck smell of sulphur, it can hardly be doubted but that sulphur is the principal inflammable matter that enters the composition. The colour of the flame, and the crackling noise that follows the thunder, shew that it is not pure sulphur, but that there are other exhalations mingled with it, which being set on fire in the open air, are exploded with a crash. Art has discovered, that balsam of sulphur is of the same nature, when agitated by too much fire in close vessels, and then cast out. We know many things, that being fired in the open air are exploded with a bounce. Such are *aurum fulminans*, *orpiment* with nitre and salt of tartar; diaphoretick antimony with black soap^a, *pulvis fulminans*, iron dissolved in *aqua regia*, and mingled with salt of tartar, lead dissolved in spirit of nitre, &c. and we know many other things, which set on fire in a close place, flash with a noise, as gun-powder, arsenick digested with spirit of nitre, *Geoffrey's* spirit of nitre mingled with any distilled oil; as also all oils and spirits, which are forced by a too vehement fire in close vessels. Perhaps nature makes use of many other exhalations and inflammable substances mingled with sulphur, to perform the same effects; therefore all thunder will not be the same, but very different in different countries.

§. 1342. Almost every country exudes sulphureous steams out of itself into the atmosphere, together with many other exhalations, which may enter the composition of thunder. Great plenty of salts float in the air, especially the *matrix* of nitre, which doubtless meet with sulphureous and

^a L'Hist. de l'Acad. Roy. An. 1736.

other exhalations, which are mingled with them. What other exhalations must concur to the forming of thunder would be rash to determine. Whatever they are in what follows, I shall call them the *matter of thunder*. The tracts of this, although they fly about in the atmosphere in the form of exhalations, are as it were lines formed of gun-powder, the flame beginning at one end, follows only it's own aliment of fire, and runs through all the grains to the other extremity, till the whole powder is fired. In like manner the inflamed tracts of thunder, which are suspended in the air, flash with a flame that runs from one extreme to the other, wherever the vein of nourishment leads it. Hence those rays of thunder, which seem to be brandished through the air, and sometimes to be split into two or more tracts, and sometimes to return back, at other times to be projected in lines that are joined by various angles; and this only because the flame meets with tracts lying in various situations that cohere with one another. Therefore thunder seems now to run horizontally, now from above downwards, now upwards from the earth. For if the matter of thunder perspiring out of the earth is inflamed near the ground, the flame darting upwards, the thunder will seem to be projected out of the earth. If the same tract were set on fire at it's upper end, the flame will move downwards, and the thunder will seem to descend out of the sky.

§. 1343. Wherefore thunder will be observed chiefly in those places, where the fulmineous matter expires out of the ground. Yet this when expired, by means of the wind, may be transferred to other countries, and there take fire. Hence it thunders in some places oftener than
in

in others, but most frequently in those the soil of which is parched by the hot sun, and which exhale various oils and plenty of sulphur. And seldomer in places, which within have neither oils nor sulphur, or in watry, moist, and cold countries. In *Egypt* and *Ethiopia* it seldom thunders; in *Sicily* and *Italy* very frequently^a. But why does it thunder in the midst of the ocean? Because from the bottom of the ocean vast tracts of sulphureous matter are cast up through the waters, as it happens to spring-waters in several places, the waters of which will take fire from a lighted candle^b. For sulphureous exhalations burst out together with the waters. The fulmineous matter in the air is set on fire, when it meets with exhalations or vapours, with which it can excite a vehement effervescence.

§. 1344. Because in these countries the exterior cortex of the earth is constringed by the winter's cold, snow, and ice; sulphur cannot perspire much from the inner parts of the earth in winter time, or any other fulmineous matter. Hence with us in winter it seldom or never thunders. But as soon as the earth begins to be opened by the sun in the spring, something expires in the month of *April*, which takes fire. But by the greater heat of the sun penetrating deeper into the earth, the cortex is more opened in *May*, and now there is a more copious expiration of the fulminating matter; and whatever was collected and shut up in winter is now released, and is snatched up into the air, and thence proceeds the most frequent thunder in the month of *May*, and

^a Plin. l. 2. cap. 51.

^b Comment. Bonon. p. 119. Lucretius, lib. 6. Philos. Trans. N. 334.

chiefly when a very hot day or two has gone before. A less quantity of the same matter remains in the upper cortex of the earth for the month of *June*, but in the mean time a new stock arises out of the deeper bowels of the earth, which is attenuated and prepared, so that by the very fervent heat of *July* it is elevated as it were in heaps, and set on fire. Hence thunder is as frequent in *July* as in *May*. And the heat then decreasing in the succeeding months, the exhalation of the fulminating matter out of the earth is more sparing, and thence also the thunder is less frequent; till in *October* and the other winter months the earth is bound up with us, and hardly expires any more. Hence we see why it very seldom thunders when the northerly winds blow; for these winds constringe the earth with their cold, and so hinder the fulminating matter from bursting forth, or when they are burst forth and floating in the air, they hinder their effervescency. But on the contrary when the warm and moist south wind blows, which opens every thing, the earth likewise is opened, and abundant fulminating matter is expired and ascends on high, which is there easily inflamed.

§. 1345. The flame which begins at one end of the fulmineous tract, as it runs very swiftly through the whole tract, seems to carry along with it some parts, which it could not easily set on fire. When it has accumulated these in a good quantity, and in the mean time very much heated them, so as to cause them to burn likewise with the other matter; then being set on fire they are dislodged with a sudden and great violence; thus that great crackling noise is made which we call a *thunder-clap*; for after the thunder or flash-

ing is ceased, the thunder-clap immediately follows.

§. 1346. Does not that accumulated fulmineous matter, not yet all on fire because of it's quantity, form those fiery balls, which have been observed to fall out of the sky by their own gravity, in places that have been thunder-struck? Have not these been afterwards so heated, as suddenly to have taken fire through their whole substance, and by their dislosion to have committed great ravage, and have been the occasion of great destruction and desolation^a? This seems probable to me, from the observations made by myself and others. Yet it must be confessed, that these balls are not seen every time it thunders; for they are either too small, or too far off, to be always seen, and the matter of thunder is different from it.

§. 1347. Though a thunder-clap is but one single sound, yet it is often heard in the form of a great murmuring noise of a long continuance; sometimes for 30 or 40 seconds, because of it's various repercussions^b by the clouds and terrestrial obstacles. Hence it is that in vales, which are surrounded by mountains of different height, there is a terrible and long-continued bellowing of thunder-claps; whereas for one explosion it has been observed that there is but one clap. Yet however if the flame sets fire to two, three, or more fulmineous tracts, each of them at last will end in a clap, and thus several sounds may be heard together, or quickly succeeding one another.

^a Philos. Transf. N. 316, 319, 336, 357, 390. Collect. Bresslau. An. 1717. p. 157. Miscellan. Berol. Contin. 2. p. 2. p. 114. Scheuchzer. Meteor. Helv. p. 24, &c.

^b De l'Isle Memoir. Physic.

§. 1348. From this doctrine we may plainly perceive, first, why it may fulminate and thunder when the sky is clear. Though this seldom happens, and *Lucretius* denies it^a; yet that it has happened is taken notice of by some of the ancients, as *Homer*^b, *Horace*^c, *Virgil*^d, *Cicero*^e, *Ovid*^f, *Alex. ab Alex.*^g, *Pliny*^h, *Julius Obsequens*ⁱ; and among the moderns *Scheuchzer*^k. For the sulphureous exhalations may always take fire, as soon as they have burst out of the earth, whether the sky be serene or cloudy.

Secondly, it manifestly follows, that thunder and thunder-claps are not always generated in the clouds, nor inhere in them, unless the fulmineous exhalations ascend thither also. For *Maffeus*^l and abbot *Lionus*^m have seen thunder to mount on high from the earth. The ancients without doubt have seen something like it; for *Seneca*ⁿ calls that *infernal thunder*, when the fire arises out of the earth. The burning mountain *Vesuvius* has been seen to emit thunder^o; and such fires have broke out of mines. But lightning immediately following a thunder-clap, shews that the noise is not in the clouds, but is excited in that place where the thunder ceased. This is entirely confirmed by the fulmineous ball, which by it's explosion excites a thunder-clap.

^a *Lucret.* l. 6. v. 246, 400.

^b *Odyss.* v. 112.

^c *Carminum*, lib. 1.

^d *Georgic.* l. 1.

^e *De divinat.* l. 1.

^f *Fastor.* l. 3.

^g *Lib.* 5. cap. 3.

^h *Hist. Nat.* l. 2. c. 51.

ⁱ *De Prædigiis*, c. 83.

^k *Meteor. Helvet.* p. 2.

^l *Litter. Maff.* ad Valisner.

^m *Diar. Italic.* T. 32. A. 8.

ⁿ *Senec. Qu. Nat.* l. 2. c. 49.

^o *Philos. Transf.* N. 337.

Thirdly,

Thirdly, there are generally thick and black clouds produced in the sky, which are agitated by various motives in all directions, before it begins to fulminate and thunder, as also during the tempest; from whence we are used to derive some kind of presage of thunder at hand. But these arise from the effervescency, when they meet with the fulmineous exhalations; and hence those labours, as we may call them, of the air; while the particles of vapours scattered in it's interstices are expelled and condensed, they compose thick and black clouds. As soon as these are more compressed to one another by the inflamed thunder, they are thickened into hard rain, which generally accompanies thunder and thunder-claps.

Fourthly, but the repeated displosions of thunder expel with great violence the air every where out of those places, into which, as into a *vacuum*, other air immediately rushes. Hence those furious winds and storms, which go along with and follow thunder.

Fifthly, how is it that men and other animals, when struck with thunder, fall down dead and are killed without any token or mark of the thunder? Is it because they are stupified by the dread of that terrible noise and fire, in the midst of which they find themselves, and so lose their senses, and then their lives also? Or because they are suffocated by the spirit of the burning sulphur, which is a mortal poison to all animals? Or because the exploded thunder forces the air out of that place, or destroys it's elasticity^a, so that the animals are left *in vacuo*, or in air that is

^a Hales's vegetable Staticks, p. 227.

not fit for respiration? Perhaps all these three causes concur together, or every one in particular may be fatal. Sometimes animals that are thunder-struck have deadly wounds and contusions, which are conspicuous, and then the cause of their death is manifest.

Lastly, since therefore thunder is a real flame of the burning fulmineous matter, it is not at all to be wondered, that it should set on fire any combustible bodies it meets in it's way. That it should melt metals, that it should rend, beat down, pull up, and cleave bodies of any resistance. And since most subtile exhalations ascending out of the earth can easily penetrate through wood, bricks, and walls; it is also plain why thunder has been seen to run through roofs, partitions, floors, and cielings of houses, because the fulmineous tract of exhalations had run that way before. But many more things may be easily explained from the premises, such as these. How from seeing the flash, and from the time between to the hearing of the clap, it may be known how far we are distant from the place of the explosion of the thunder. See §. 1151. Why there is the utmost danger, when the clap is heard at the same time as the light or thunder is seen. Why when the noise of thunder is vehement, a trembling seizes houses and most other bodies. See §. 1168, 1169. Why some fluids ferment at the time of thunder, and others cease to ferment, which before were in fermentation. Why many are corrupted by thunder, though laid up in cellars. How thunder may be diverted to another place, and in some measure prevented by the sound of many great bells, as also by the discharging of great guns. Though at another time it appears, that the ringing of bells had

no effect ^a. The very learned *Richterus* has treated of this subject in a most elegant manner, in his discourse of the origin of thunder.

§. 1349. The use of thunder and thunder-claps is first to purify the air from sulphureous and oily exhalations by it's inflammations; by attenuating and changing the exhalations, by firing them, that they may not be injurious to the life and health of animals, but rather may be beneficial to them, as also to the vegetation of plants. Therefore the rain that falls at that time, and carries with it the burned parts of the fulmineous matter, is thought to be more fertile than any other rain. Secondly, thunder moderates the heat of the atmosphere; for it has always been observed, that cold follows in a few hours after. Before it thunders the air is always in an effervescency, and is hot; but when the thunder is consumed, the effervescency is appeased, and hence proceeds coldness. Though this seems also to be occasioned by the spirit of nitre, produced by the burning of nitre and sulphur.

C H A P. XLI.

Of airy Meteors, or of Winds.

§. 1350. **A**S often as any tract of air moves from the place it is in, to any other, with an impetus that is sensible to us, it makes what we call a *wind*. Wherefore it was not ill said by the ancients, *a swifter course of air; a flowing wave of air; a flux, effusion, or stream of air* ^b.

^a L'Hist. de l'Acad. Roy. An. 1719.

^b Hippocrat. lib. de Flatibus. Senec. Qu. Nat. 1. 5. c. 6.
Therefore

Therefore the wind does not consist of mere vapours, or exhalations, or of a certain specifick substance, of blind and obscure bodies ^a, of cold breathings of the earth ^b, different from the air, as many Philosophers have imagined; but it is a part of the atmosphere, with all it's contents, removed from one place to another. Whatever therefore drives the air forwards, raises a wind. Therefore whether vapours, exhalations, or whatever else is in the air, and are moved forwards, the air itself being very moveable which they meet with, will also move.

§. 1351. If an inhabitant of the earth conceives himself as placed in the middle of his horizon, in respect of him the air may move upwards, downwards, with all degrees of obliquity; also horizontally with infinitely different directions, as from the center of a circle radii may be drawn to every point of the circumference. Therefore the winds may have very different directions to each other. As Mathematicians have divided the circumference of a circle into a determinate number of parts, so likewise the coasts of the winds have been divided; particularly for the use of mariners, the moderns have thought 32 coasts or points to be sufficient. But some of the ancients only made 6 ^c, others 8, as *Andronicus Cyrrhestes*; *Aristotle* made 10 ^d, others 12 with *Varro* ^e, others 24 ^f, but not so conveniently. Since in our age we have made a new division, the ancient names do not agree

^a Lucret. Lib. 1. v. 278.

^b Cicero de Divinat. C. 6.

^c Strabo, Lib. 1.

^d Lib. 5. c. 16.

^e Senec. Qu. N. 1. 5. c. 16.

^f Vitruv. 1. 1. c. 6.

with the modern direction of the winds, which yet *Kircher* has endeavoured to accommodate to them^a. Therefore that no controversy may arise about the name, we according to our observations have chiefly attended to 8 points, and thus call them. The wind blowing from the equinoctial sun-set, is *Favonius*, or the west-wind; from the winter setting, is *Africus*, or south-west; that blowing from the meridian, is *Auster*, or the south; from the winter sun-rising, is *Eurus*, or south-east; from the equinoctial-rising, is *Subsolanus*, or east; from the solstitial-rising, is *Aquilo*, or north-east; from the seven stars is *Septentrio*, or north; from the solstitial-setting is *Corus*, or north-west. Therefore we conceive the winds as coming from another place to our own, but the point to be extended from our place to another.

§. 1352. The winds are conveniently divided, first, into general and constant, secondly, anniversary, thirdly, marine and terrestrial, fourthly, free or wandering, having no settled course.

§. 1353. A general wind blows between the tropicks of *Cancer* and *Capricorn*, or something wider, upon the *Atlantick*, *Ethiopick*, *Pacifick*, and part of the *Indian* ocean. In other regions of the earth are anniversary winds; and in those countries that lye without the *tropicks*, the free winds are observed. The history of the general wind has been delivered very well by the learned *Halley*^b, and by *Dampier*^c, whom as guides we shall here follow. But for a clearer understanding of them it may be necessary to inspect Tab.

^a Ars Magn. 1, 2. par. 6.

^b Philos. Transf. N. 183.

^c Traité des Vents.

9. in which the arrows placed in shaded lines note the course of the wind.

1354. In the *Atlantick* and *Ethiopick* ocean, between the two *tropicks*, or a little beyond them, through the whole space of the year the east wind blows, yet so, as that here it seems to come partly from some northern point, and there from a southern point.

For first, as soon as the sailor has passed by the *Canary* islands, about the 28th degree of northern latitude, they find a north-east wind, which seldom inclines much farther to the north, yet at some times it approaches nearer to the east.

Secondly, they that go to the *Caribbee* islands find this north-east wind to incline nearer to the east, the more they approach towards *America*; so that sometimes it changes into a true east-wind; nay, sometimes inclining to south-east. Yet often it sometimes verges to north-east, and presently blows more mildly.

Thirdly, the limits of this wind extends wider towards the shores of *America*, than *Africa*; for on the *American* shores they reach as far as 30 or 32 degrees. Also on the southern coasts of *America* they have found the general wind to extend farther, than at the promontory of *Africa*, called the *Cape of Good Hope*.

Fourthly, in the northern latitude of 4 degrees, as far as 28 degrees of southern latitude, the south-east wind always blows, sometimes approaching to the east. But near *Africa* it always blows more southerly than near the coasts of *Brazil*; for the nearer it comes to these, so much the more it verges to the east.

Fifthly, these winds undergo some change according to the different season of the year, and

they follow the sun. For when the sun is between the tropick of *Cancer* and the *Equator*, the north-east blowing in the northern part of the earth, approaches nearer to the east. And the south-east, which blows upon the *Ethiopick* sea, then comes nearer to the south. On the other hand, when the sun dispenses his copious light to the southern hemisphere of the earth, the north-east winds in the *Atlantick* ocean become something more northerly. And the south-east in the *Ethiopick* ocean incline more to the east.

Sixthly, but here it must be observed, that the south-wind blows about the coasts of *Africa*, that is, *Caffaria*, *Angola*, and *Biafara*. And at the distance of 100 leagues from the coasts of *Guinea*, the south-east is changed into south. And farther from the shores of this country, the south is changed into south-west. About the shores of *Nigritania* the north-east is changed into north-west.

Lastly, on the northern side of the *equator*, between the 4th and 10th degrees of latitude, and between the meridians which comprehend the islands of the *Hesperides*, there is a part of the ocean in which thunders, showers, storms, and calms, have dominion, which succeed one another very suddenly, winds often blowing at the same time which have all manner of directions. All these things will be best apprehended from an inspection of Tab. 9.

§. 1355. The sun is the cause of this general wind, the action of which we shall clearly conceive, if we suppose him first to be in the *equator*. When he is directly over any place of the *equator*, he heats and rarifies the air vehemently, and gives it greater force. Hence it expands itself every way, and ascending upwards mounts

above the rest of the atmosphere, and flows about laterally by the law of gravitation. Hence the hot and rarified column that remains, presently becomes shorter, and with less force resists the neighbouring columns, which then by their density and weight, and also by the over balance from the air pressing from above, move to the middle heated air. In the mean time the sun advances from east to west, or rather the earth with a contrary motion, which in this case is the same thing, if we do but consider the air which grows hot successively. Therefore there must be a region in some longitude, in which from east towards the west the air resists with less force, than that which urges and presses on both sides. Wherefore being squeezed here on both sides to a place less resisting, it will be carried by a double direction. That which is in the northern hemisphere of the earth will be carried by a compound direction from east to west, for a motion backwards: And by a direction from the north towards the equator. Such a compound direction will produce a north-east wind. That which is in the southern hemisphere of the earth will move with a direction from east to west, and sideways with a direction from the south towards the *equator*. Hence there will be a compound motion, by which the wind will be produced, which is called south-east. Because the heat by means of the sun is successive, nor sudden or with vehemence, a wind so raised from east towards the west will not be impetuous, but will go on with an equable tenor. It will begin where the air is not hindered from approaching sideways by mountains, woods, or other impediments; and therefore an easterly wind will begin in places of the ocean which are something re-

mote from shores. As it is observed to arise at the distance of almost 100 leagues from the coast of *Africa*. As soon as this wind begins to approach to the coasts of *America*, mountains oppose it's course ; and therefore sailors observe, that it blows so much the more gently, as they are nearer to *America*. This obstacle of mountains is the cause, that it is expanded something wider on the coasts of *America*, than it began to do near *Africa*.

Now let us go along with the sun as he illuminates the northern hemisphere of the earth, and as he inflects his course from the *equator* towards the *north pole*. Then the atmosphere which impends over the *Atlantick* ocean, being heated by the rays of the sun directly, would have been the cause of an east wind. Therefore because of the lateral appulse of the air, the north-east wind that blew before now inclines something nearer to a due east. But the air that impends over the southern *Ethiopick* ocean, and is now become colder than when the sun was in the *equator*, and therefore denser, will be urged with a greater lateral force towards the heated air, and by a motion, which is more to the south, will be the cause of changing the south-east into a south-wind.

As the sun returns from the tropick of *cancer* to the *equator*, by degrees the north-east-and-by-east wind of the *Atlantick* sea will be changed into a true north-east, because of the lateral afflux of the air to those places, in which the sun is vertical. And the south wind of the *Ethiopick* ocean by degrees will be changed into a south-east. Till the sun passing over the southern hemisphere of the earth, this south-east inclines more to an east. And the north-east of the *Atlantick*

lantick sea tends a little more towards the north. All which things exactly agree with the foregoing observations.

But an easterly wind here remains, between the two *tropicks*, or is extended a few degrees farther, that is, to the latitude of 28 or 30 degrees on each side from the *equator*. Because now the sun darts his rays perpendicularly upon the land and the air, lying between the *tropicks*. But the adjacent lateral air for 4 or 5 degrees farther, is sufficient to fill up the intermediate air, that is heated by the sun; since it presently receives it rushing in from the upper part of the atmosphere, which by it's quantity supplies whatever the other had lost by expanding itself.

§. 1356. It will be more difficult to assign the true reason of the southerly winds, that blow near the shores of *Cassaria*, *Angola*, and *Biafara*. Also why not far from *Guinea* the winds are changed to west, or south-west, as those on the shores of *Nigritania* are changed into north-west. Perhaps these arise, because the soil of *Guinea* and *Biafara* being very sandy, is vehemently heated by the sun, and retains it's heat a long time. Therefore the air that is over this hot soil is much rarified, ascends and disperses itself sideways on the superficies of the atmosphere. The lateral air which can most freely approach to that which is over *Guinea* and *Biafara*, is that which incumbs on the ocean near the coasts of *Cassaria* and *Angola*, and which therefore moving towards *Guinea* produces a south wind. But the nearer it approaches to *Biafara*, so much the more it is determined to this region, and is changed into a south-west. In a like manner part of the easterly wind in the free ocean, not far from *Guinea*, because of the air of this region having much less resistance, is
inverted

inverted, and by a contrary direction is drove towards the west, and also changed into a south-west. The country of *Nigritania* has it's soil not different from that of *Guinea*, and therefore the air of the *Atlantick* ocean will be determined towards these shores. Whence not a north-east but a north-west will blow from the island *Palma* to the shores of *Billedulgerid* and *Nigritania*.

§. 1357. We have before mentioned a place in the *Atlantick* ocean, between the north latitude of 4 and 10 degrees, in which calms and storms exert themselves. It is here that there is an equilibrium between the general eastern wind, and the south-west, tending to *Guinea*, and therefore here the air is at rest. However since very frequent thunders and thunder-claps are observed here, the bottom of the ocean must send forth a great quantity of bitumen, sulphur, and fulminous matter. This continually making an effervescence and taking fire, will sometimes raise a wind, now to this quarter and presently to that, or that will blow to any quarter. At last the matter being exploded, the air will return to it's former tranquillity.

In the mean time the clouds will be brought by the general wind to this place, and at the same time others raised from the *Ethiopic* ocean rush hither, being driven by the south-west wind. Others produced in the *Atlantick* ocean are here accumulated by the north-west wind. Wherefore the clouds here condensed by these winds with opposite directions, will be squeezed into rain. This will be very hard when it falls, since the thunder shakes the clouds still more vehemently, and forces them into close heaps, which now become very heavy, nor can they any longer be sustained by the air, but tumble downwards as
it

it were by consent. And thus showers seem to fall as it were by pails-full from the sky.

§. 1358. About the coasts of *Brazil* some other irregularities are observed to obtain. For from the month of *April* and afterwards the south-west wind blows. From the month of *September* and so on the north-east wind blows. The shores of *America*, which are more south than *Brazil* are much inflected towards the west. Therefore the south wind, which in the month of *April* blows upon the *Ethiopick* ocean, is determined by the coasts of *Brazil*, by which it is kept in, so that it is necessarily changed into a south-west. But in the month of *September* the sun impends perpendicularly over *Brazil*, and very much heats it's soil, and this the air; as in §. 1356, was said to be done in *Guinea*. Wherefore the air will be determined hither from the cold northern parts of the earth, and a north-east wind will be raised. These are the chief circumstances that concern the general wind of this ocean.

§. 1359. From hence we imagine it follows plainly enough, that the easterly wind does not arise because of the motion of the earth about it's own axis, and leaving the atmosphere behind, as has by some been thought. First, because the general wind is not an easterly wind, but a south-easterly or north-easterly, the direction of which is something changed, according as the sun varies his place in the *ecliptick*. Secondly, because the velocity of this wind is much less than that of the rotation of the earth about it's axis; for this wind is no swifter than so as to run 8 or 10 feet in a second; whereas the *equator* describes 1423 feet in the same time. Thirdly, the atmosphere does not forsake the earth in it's annual motion about the sun, but each moves with the same

same velocity. Why then should the earth leave it's atmosphere behind, in it's diurnal motion? No reason can be given for this. Fourthly, then also at the tops of mountains all over the earth an east wind would blow, which is against observation. Lastly, this opinion quite falls to the ground, because other winds blow in the *Indian* ocean; of which I shall treat presently.

§. 1360. The same general wind reigns in the *Pacific* ocean, as we have described in the *Atlantick* and *Ethiopick* Oceans. For the north-east wind blows upon the northern hemisphere, and the south-east upon the southern hemisphere. Each wind is extended as far as 28 or 30 degrees on each side from the *equator*. Yet there are irregularities on the western coasts of *America*, the westerly winds blowing here. The reason must be derived from the soil being heated, and thence the air rarified; in the same manner as we have said already in §. 1356.

§. 1361. In the *Indian* ocean there is a greater variety of winds. For in that there is a general wind, but there are periodical winds besides, which for 6 months blow towards a certain quarter, and as it were returning the next 6 months, move with a contrary direction. These are called *monsoons*, or anniversary winds; and this is the nature of them.

First, within the southern latitude of 30 and 10 degrees, between the island of *St. Laurence* and *New Holland*, the south-east wind blows the whole year round, which yet sometimes approaches nearer to the east.

Secondly, between the degrees of 2 and 10 of south latitude, between *Java*, *Sumatra*, and the isle of *St. Laurence*, in the months of *May*, *June*, *July*, *August*, *September*, and *October*, the south-east

east
6 m
T
Ara
ove
equa
from
blac
and
reig
sky.
nort
in th
F
the
wind
mon
as it
into
chan
ing f
La
Suma
April
little
April
north
west
Holla
west
by th
tra, a
As o
stand
lofs w
winds
chang

east wind blows. But from *November* in the other 6 months, the north-west wind reigns.

Thirdly, between the *African* coasts of *Ajana*, *Arabia*, and *Malabar*; also in the bay of *Bengal*, over all this part of the *Indian* ocean as far as the *equator*, an impetuous south-west wind blows from *April* to *October*, which is accompanied by black rainy clouds and storms. From *October* and the other months till *April* a north-east wind reigns, milder than the former and with a clear sky. Each of these winds, the south-west and north-east, is milder in the bay of *Bengal* than in the *Indian* sea.

Fourthly, between the coasts of *Zanguebar* and the island of *St. Laurence* there is a south-east wind from *October* to *May*; and the whole 6 months from *May* a west wind blows. As soon as it is gone beyond the island of *St. Laurence* into the open sea towards the *equator*, it is changed into a south-west wind, but little differing from a south-wind.

Lastly, between the coasts of *China*, *Malacca*, *Sumatra*, *Borneo*, and the *Philippine* islands, from *April* to *October*, a south-west wind blows, but little declining from the south. From *October* to *April* a north-east wind blows, little differing from north. Nay, it inclines to a north and north-west between the islands of *Java*, *Timor*, *New Holland*, and *New Guinea*. As instead of a south-west the south-east blows here, which as it were by the bending situation of *Timor*, *Java*, *Sumatra*, and *Malacca*, is determined to a south-west. As often as these *monsoons* are inverted, they stand still in some places, as if the air was at a loss which way to turn. But in other places the winds cease with great fury, and are immediately changed into their opposites.

§. 1362. The general wind of the *Indian* ocean is the same as we have explained in §. 1350. But Philosophers have not yet been able to assign the cause of the other *monsoons*, so as to remove all scruples about them. The *monsoons* seem to depend on several causes. On the mountains and their exhalations, which they expire at stated times, and which urge the air forwards in certain directions. Also on the melted snow, and the concurrence of many other circumstances hitherto unknown. Therefore these enquiries must be left to wiser posterity. The *Etesiae*, or the anniversary winds of some other countries, seem yet not to be well understood^a, nor can they be demonstrated, unless we were actually to view the situation of the countries, to observe the position of the rivers, mountains, seas, woods, and the course of the melted snows. For it is on these causes they chiefly depend.

§. 1363. In other countries of the earth the free winds blow, or such as observe neither time, or period, or point, or force, but are directed every way. Their cause is the same which can move a part of the atmosphere from one place to another. Their determination depends on the situation of mountains, woods, and other eminences, which direct the air driving against them into certain courses. Therefore the winds will be singular and peculiar to their own regions, nor can they be known or explained, unless the country with all things adjacent to it be first well known and described. The observations made in *Switzerland* by *Garcinus*, those at *Norimberg* by *Doppelmajerus*, and our own in *Holland* inform us, that

^a Varen. Geograph. S. 6. C. 21. Memoir. de Languedoc. p. 2. c. 8

different

different winds blow in these places at the same time, unless when a storm rages of a long continuance.

§. 1364. The soil of the seven *United Provinces* is very flat and even, without any mountains, unless at the distance of two miles from *Utrecht* there is the mountain *Amersfort*, which is but small, and of no considerable height. Yet there are found several in that part of *Guelderland* called *Velaw*. Observations made at *Utrecht* for several years, as also in other parts of *Holland*, have informed us, that the number of certain winds for the space of a year is in a manner determinable. By adding many years together I have found a medium, from which the number of winds may be known, that will not be far from the truth. According to this at *Utrecht* the north wind blows 42 days, the north-west 33 days, the west wind 77, the south-west 58, the south 33, the south-east 26, the east 53, the north-east 43. Are not the west winds and south-west thus frequent, because the *German* sea lies to the west in respect of our country, and thus the air incumbent on this sea, being colder, will be urged towards the warmer and rarer, that is over our soil? Or is it a part of the general north-east wind, reflected from the shores of *North America*, and by an opposite direction blowing up the *British* channel, and over the southern part of *England*? Perhaps each cause has it's share in it.

§. 1365. But why are there very few south-east winds with us? Is it not because our soil is more moist than that of *Germany*, which lies in this quarter, and therefore is very cold, and is much less heated than that of *Germany*? Therefore our air incumbent on the soil is also less heated, and rarifies

fies less than the air, which incumbs on the more southerly and drier country. Therefore south-east winds and south winds are raised but seldom, and north winds often, which are brought from cold to hotter countries,

§. 1366. But why do east winds blow so frequently with us? These are always cold, even though they blow in the middle of summer, and in winter time they freeze water into ice; for it seldom freezes but when an easterly wind blows. Because the air of our flat soil is hotter than that which incumbs over the mountainous parts of *Germany*, lying in an eastern quarter in respect of us; a denser and colder air will be drove very frequently to our region, and will there raise an easterly wind. Or will it be rather a part of the general wind? Why also are the north-west winds so rare with us, which are so pernicious to our dikes? Is it not because they are intercepted by the mountainous country of *Scotland*? Whence the winds that blow to us are chiefly north-east, which falling upon the mountains of *Scotland* are reflected to us. There is an old tradition, that that wind will continue with us for the space of 14 days, which blows at the time of the vernal *equinox*, chiefly if it is a north-west or a north-east wind. But accurate observations made by me at *Utrecht* have taught me this is only a fiction.

§. 1367. The causes of free or vague winds are either in the bowels of the earth, or in it's superficies, or in the atmosphere, or above it. Many observations evince, that the earth itself emits a great quantity of air, and breathes it out of it's inward parts. *Pliny** testifies this of *Senta*

* Hist. Nat. l. 2. c. 45.

in *Dalmatia*, and of a rock in the Province of *Cyrene*. And *Gilbert* asserts the same thing of some caverns in the county of *Denbigh* in *Wales*, out of which there are such violent eruptions of wind, that if a cloth is opposed to them it will be blown back with great force. *Scheuchzer*^a has described several *Æolian* caves, that expire wind out of the inner recesses of the earth. *Connor*^b tells the same thing of that of the *Cumæan* sybil in the kingdom of *Naples*. As also of the caverns at *Bayæ*, of some mines in *Germany*, and of the salt-works at *Cracow*. It is so likewise near *Terni*^c, and in *Vesuvius*^d, and in *Catalonia*^e. Also others acquaint us, that winds ascend out of the bottom of the sea, break through the water, and burst out into furious whirlpools. As *Gassendus*^f of the lake *Legni*, *Hearnus* of the *Weter* in *Sweden*^g, also of the *Chinese* ocean^h.

§. 1368. The causes of the winds that issue out of *Æolian* caverns may be many. For a cavern may be considered as a large vessel with a capacious belly, but a narrow neck. Let it be full of cold dense winter air. Therefore as soon as the atmosphere above the earth is lighter, immediately the air, now less pressed than before, will burst out of the belly of the vessel, being driven through the neck by it's own elasticity, and will imitate a wind blowing upwards. Or let water drop like a rivulet through

^a Stoicheiograph. Helvet. p. 122.

^b Differt. Med. Physf. p. 33. a. 3.

^c Kircheri Mund. Subt. l. 2.

^d Misson. Itin. Tom. 3.

^e Marc. Hispan. l. 2. c. 22.

^f Vita Piereisk. l. 5. p. 417.

^g Phil. Transf. N. 298.

^h Obs. Physf. of *Siam* Embassad.

the chinks of the earth into a hollow cavern. The water will carry much air with it, by which it can raise a strong wind, that is not to be imitated by a large pair of bellows; as formerly was tried by *Hero*. This afterwards will burst out at the mouth of the cavern. In caves if water falls upon earths impregnated with sulphur, iron, or the pyrites, presently a heat will be produced, and the water changed into a very elastick vapour, expelling the air with violence out of the cave, and then itself will gain a passage by these vents, to our habitations. As water heated in the colipile bursts out at a small hole in the form of wind; so subterraneous fire, whatever produces it, will perform the same thing. If several *Æolian* caves communicate with one another, and every one is provided with it's own vent-holes, it cannot be otherwise but that one shall receive wind from the upper atmosphere, which it will send through the whole cave to the opposite open vent, or this other vent will perform the same thing. The causes of winds bursting out through the waters are earthquakes raised under the waters, which proceed from effervescences and inflammations, by which much elastick fluid is generated, and is driven upwards with great violence. When this breaks forth out of the surface of the water, it expands itself with much vehemence.

§. 1369. All things which can move the air are to be referred to the causes of such winds, as are upon the superficies of the earth. Such are the waves of the sea, rivers; whence upon the banks and shores are always winds stirring. Also exhalations and vapours ascending out of the earth, a fire raised, the melting of snow and ice by the sun, and innumerable other things.

§. 1370. Many winds are raised by causes that inhere in the atmosphere itself, which may act in various manners. The principal cause consists in the effervescency of various exhalations meeting one another, or in the mixture of exhalations with vapours, and the effervescency that thence arises. But no sooner do two exhalations excite an effervescency with each other, but they will be dilated, expanded, and require more room, and so will beget an elastick fluid, driving the air with a greater or less celerity, according to the different force of the effervescence, and the action of the generated elastick fluid. Hence always winds arise when it thunders and lightens. Because a various quantity of exhalations, now more, now less, is mingled together, and after one mixture is made, some time intervenes before another is made; there arises at first a stronger, and then a milder gale; and the force being again interrupted, after rest it will soon be more impetuous. This is observed of every free wind, which never continues for two minutes at the same stay, but exerts different strength. And this the rather obtains, the stronger it is. If the exhalations are but few, so as not to make the air thick and dark, the winds are generally the milder. But if they are plentiful enough to form themselves into thick clouds, they will generate more impetuous winds. Therefore more winds are observed in cloudy weather than in fair and serene. There are clouds that raise an effervescency with every thing that is moist. These produce winds in whatever places they pass over. They are often observed in summer, though the sky be otherwise serene, and are distinguished by sailors at a distance. Now though the air will rush every way, as is often the case, yet it chiefly di-

rects it's course thither, where it has a freer passage, and where there is most room and a wide area. Black clouds are often the cause of the hurricanes, which are sometimes observed to rage violently in the *Ethiopick* sea, and in the extreme promontory of *Africa*, as *Guinea*, *Lowango*, and *Guardasu* ^a.

§. 1371. Very often here and in the foregoing we have made mention of the effervescence, which happens in the air. Now lest any one should doubt of the truth of it, he may make a few experiments to be convinced, that we have assumed nothing but what really obtains in nature. Let him set before him an open phial, in which there is spirit of sal ammoniac; something will fly away, which may rather be perceived by the smell than by the sight. It will be the same if spirits of nitre be examined in the same manner. But if we set the two phials near one another, the two exhalations meeting in the air will now excite a conspicuous effervescence, and raise a cloud. The excellent Dr. *Hales* ^b tells us, that he poured spirit of nitre to vitriolick mineral, whence an effervescence arose; which being appeased, and the air being now transparent, new air was admitted; presently the effervescence was renewed, and the air became turbid and ruddy. And this experiment might have been repeated several times with the same success. The same thing may be observed in a phial, in which is the filings of iron and spirit of nitre: or in a receiver, in which aqua fortis stayed behind, after it had been poured to pyrites.

§. 1372. The causes above the atmosphere that excite wind, are the sun and moon, which attract-

^a Varen. Geograph. S. 6. C. 21. §. 10.

^b Append. ad Haemastat. Exp. 3.

ing by their gravity, communicate a perpetual motion to the air, such as they do to the ocean, and thereby raise the tides. Yet in the atmosphere, because of the rarity of the air, the tides will be but small. Besides by it's heat the sun rarifies the air, and so much the more vehemently as it acts upon it with more rays, and those perpendicular. Therefore because of clouds that here and there intercept the rays of the sun, the air of the same region will not be equally heated or rarified. This will necessarily produce winds, since the law of the equilibrium of liquors requires, that there should be an equal action upon fluids, that they may continue at rest. Therefore the air that is most rarified by the sun, will be urged towards the air that in the day-time was under the clouds. And on the contrary, the air that by night was below the clouds, will betake itself to other air, condensed by the cold that applied itself to it.

§. 1373. A soft gale seldom travels far. But a strong wind of a good continuance has been observed to pass over a long tract of the heavens, over *England*, all *Germany*, *Switzerland*, and perhaps the countries beyond: As it appears from comparing the observations of *Scheuchzer* and *Derham*^a. But the wind that was violent in one country grew much milder in others.

§. 1374. The velocity of free winds is very different. Some move with such rapidity as to throw down trees and woods, and by Mr. *Mariot*'s observation pass over 32 *Paris* feet in a second of time. But it is collected from Mr. *Derham*'s more accurate observations^b, that the most impetuous winds move with so great rapidity, as to describe

^a Philof. Transf. N. 321.

^b Philof. Transf. N. 313.

66 *English* feet in a second, and 45 *English* miles in an hour. These winds indeed are raging, and rush with such force, as to break a pillar of stone 12 feet high, 5 broad, and two feet thick, and to demolish whole woods^a. There are other winds so slow, as not to keep pace with a horseman. Others are moderately swift, as to complete only 10 *English* miles in an hour's time. There are many more things that might be said about winds. How the knowledge of them may be attained, the great *Verulam* has taught us in his History of winds, and has given us a most perspicuous and instructive example; than which in natural philosophy there is hardly any thing more complete.

§. 1375. The use of the winds is great. First, that the air in which we live, and which is defiled by our exhalations, may be removed and brushed away, that other more pure may succeed in it's place, fitter for the purposes of life, and that the whole by continual motion may be rendered more beneficial. For if the air stagnates, especially in summer, it becomes corrupted, and contagious diseases and pestilences prevail every where; as many physicians, after *Hippocrates*^b, have informed us.

Secondly, the winds temper and refresh the air, after it has been parched by the heat of the sun; so that those countries, which would otherwise be uninhabitable, now become fit for habitation. Thus in the *East* and *West-Indies*, the sea-breezes blow in the day-time, and in the evening the land-breezes refresh and cool the air, land, and water. In our own countries in the summer, many labourers and husbandmen would perish, if

^a Philof. Transf. N. 114.

^b Lib. 3. Epidemic.

they were not refreshed by the wind. When this lies still, the heat is sometimes fatal *. Therefore the wind preserves us from the severity of the hottest time of the year.

Thirdly, the winds transfer heat and cold from one region into another. Hence with us the south wind brings heat, the north wind blows cold.

Fourthly, the winds that are dry make all moist things dry, by which means we mortals are much benefited on many occasions. The winds that are moist, gently moisten all dry things, by penetrating into the pores of bodies; nor are these without their use.

Fifthly, the clouds formed of the vapours of the ocean are carried by the winds to all regions, that they may supply the earth with showers, by which all plants grow, live, and are nourished. Also the winds hinder the falling of too great quantity of rain. For sometime they bring clouds, and sometime carry them away, so that rain may be distributed all over the face of the earth. In like manner they carry the exhalations, breathed out by the earth, to other distant regions, by which the impurities of the air are discharged. And such things as may contribute to a more plentiful vegetation, are not confined to one place, but become common to all.

Sixthly, God has given us winds, that we may know things that are at a distance from us. For man would be an ignorant animal, and without much experience, if he were to be circumscribed by the limits of his native soil. Therefore God gave us winds, that by the navigation of ships we might be supplied with all the conveniences of life, and that we might enjoy many transmarine things we should stand in need of. That

* Derham Theolog. Phys. l. 1. c. 2.

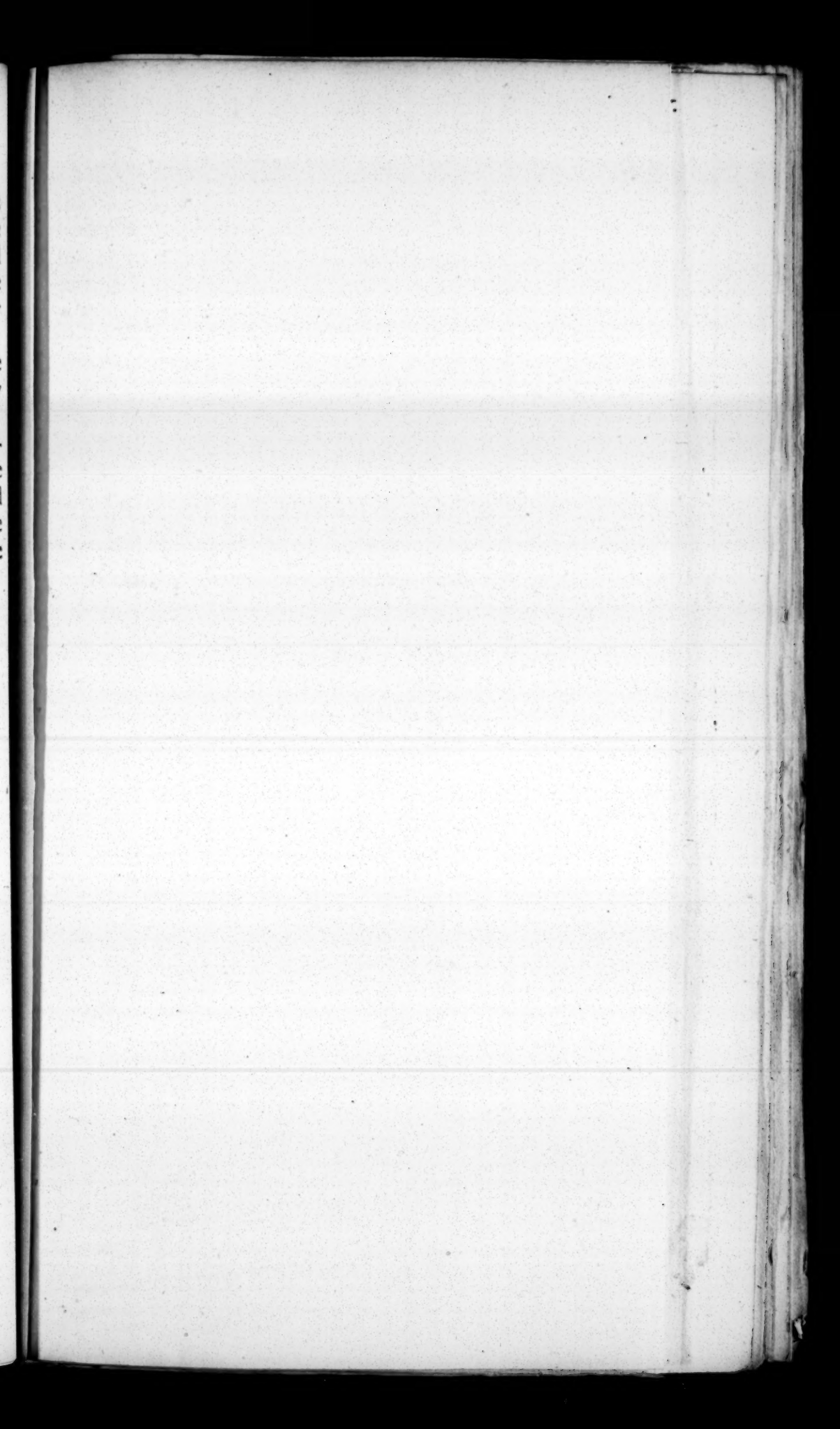
all mankind might have the benefit of such things as are produced in distant regions, that there might be intercourse among remote nations, and that thus the power, wisdom, and munificence of our liberal Creator might be more generally known and acknowledged.

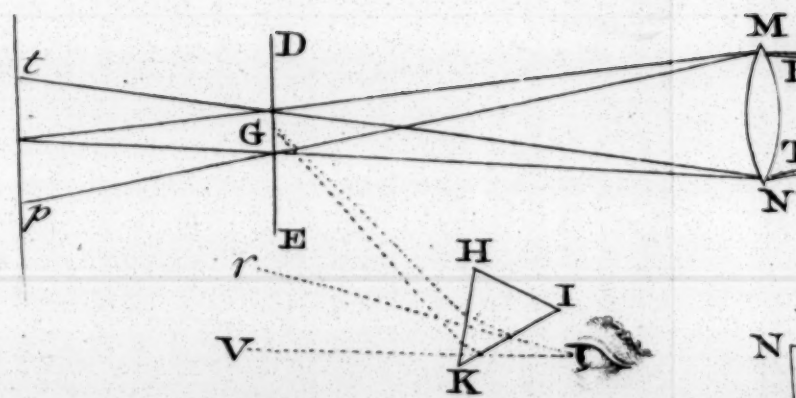
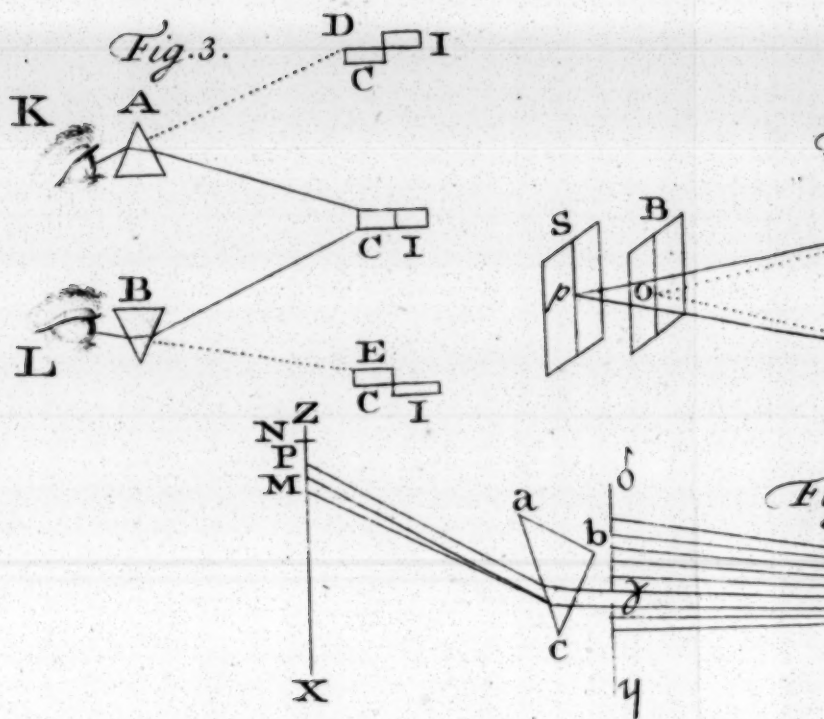
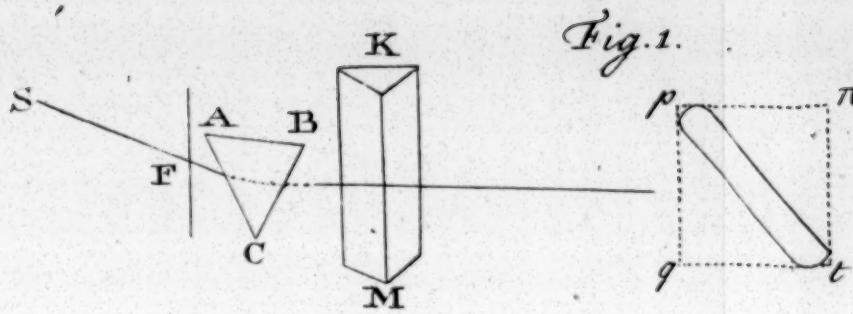
Seventhly, the winds move the waters of the ocean, of ponds, lakes, and ditches, that they may not stagnate, and so corrupt and stink.

Eighthly, by the help of the wind many machines are moved, and mills work ; by which the labour of men is spared, to their great ease and comfort. But who can enumerate all ? It were easy in these things to be more prolix ; but the nature of this compendium does not permit it.

F I N I S.







N
P
Q
R
S
T
M

Fig. 2.

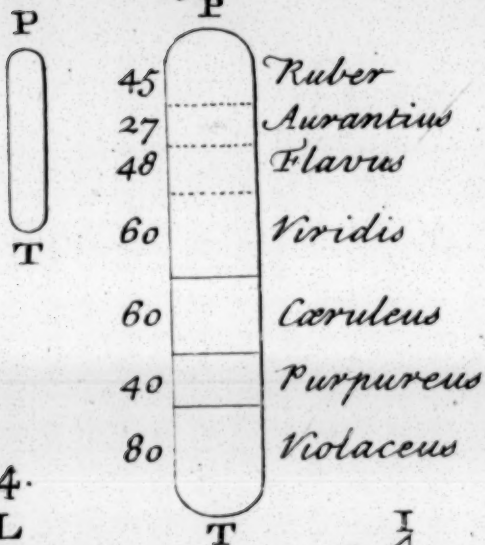


Fig. 4.

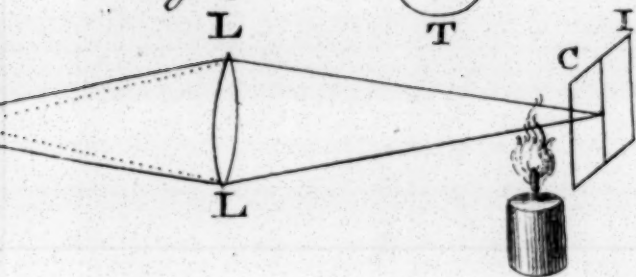


Fig. 5.

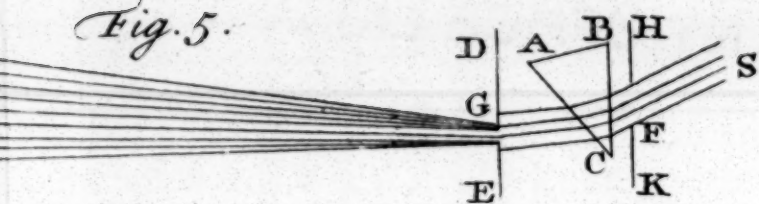


Fig. 6.

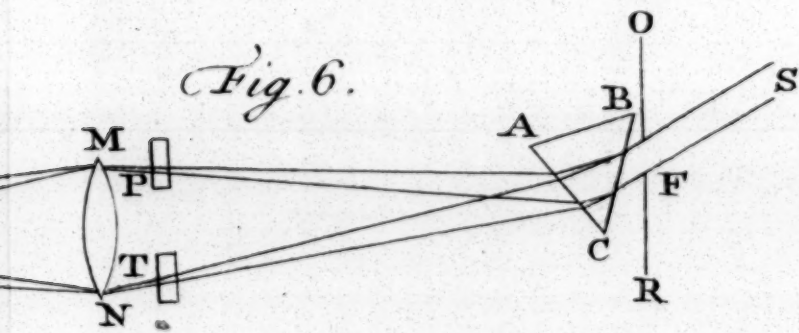


Fig. 7.

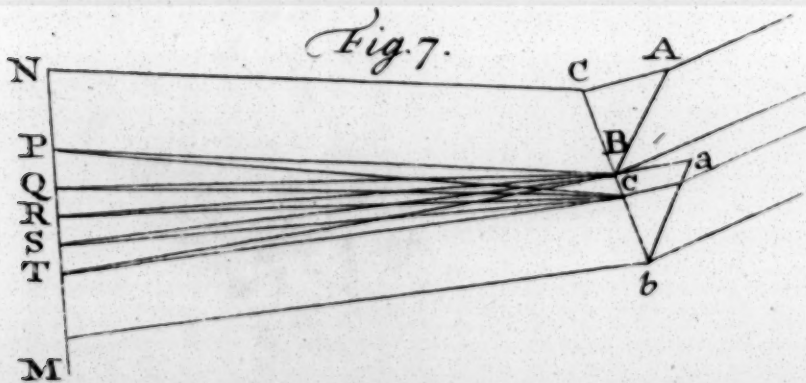


Fig. 1.

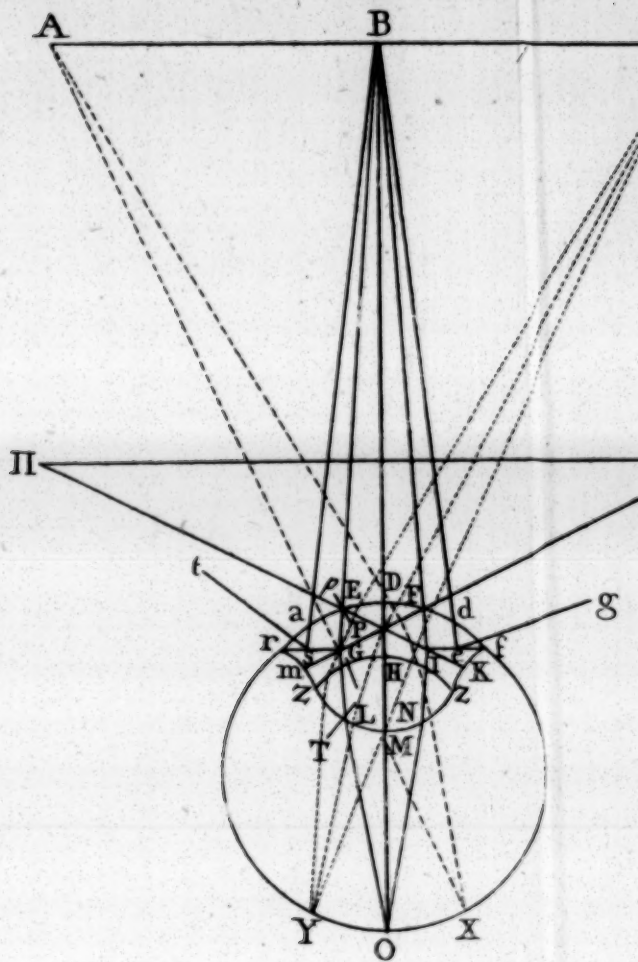


Fig. 3.

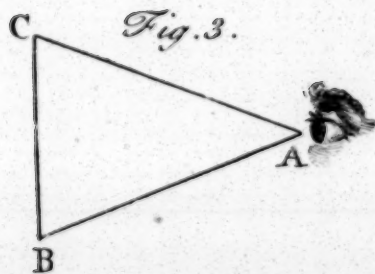


Fig. 4.

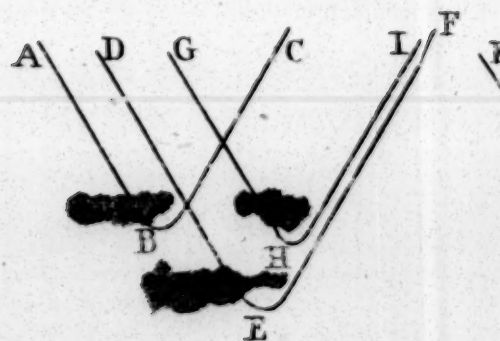
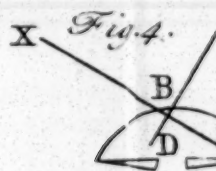


Fig. 2.

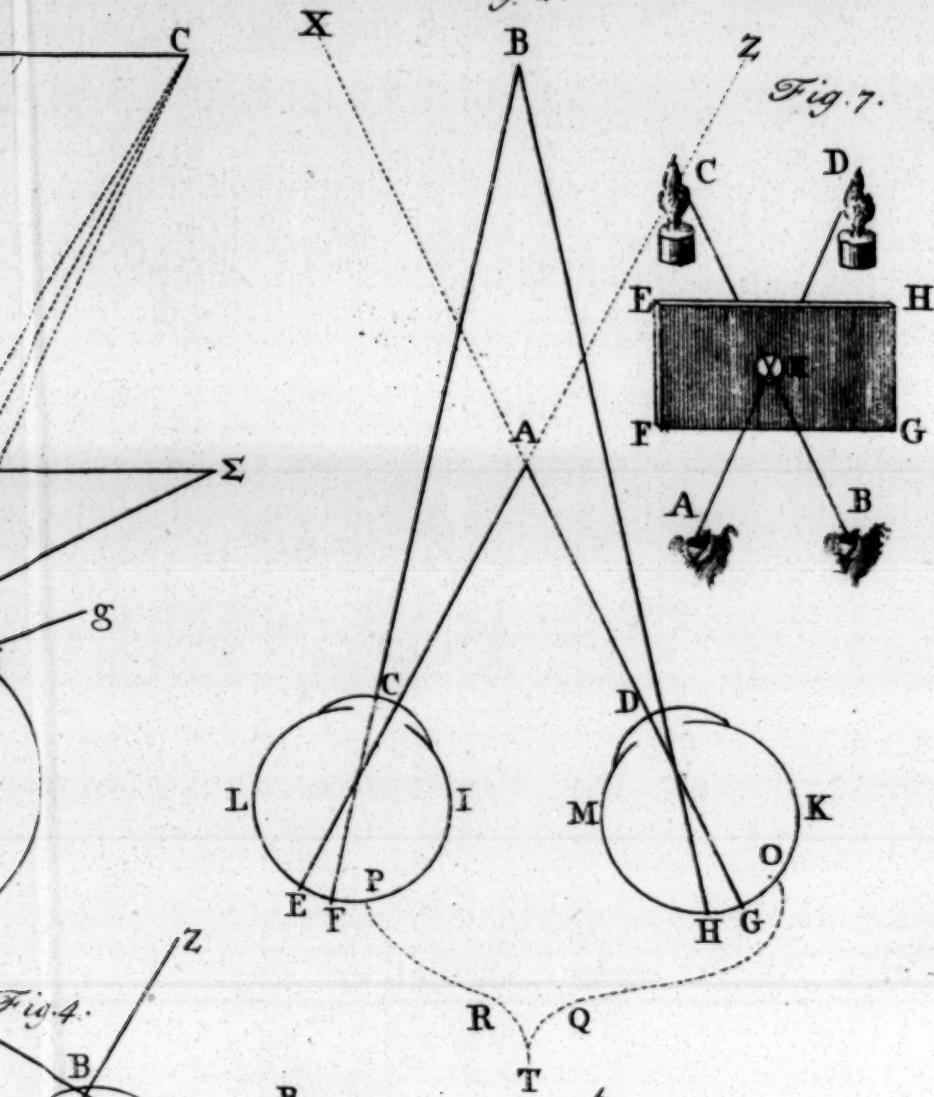
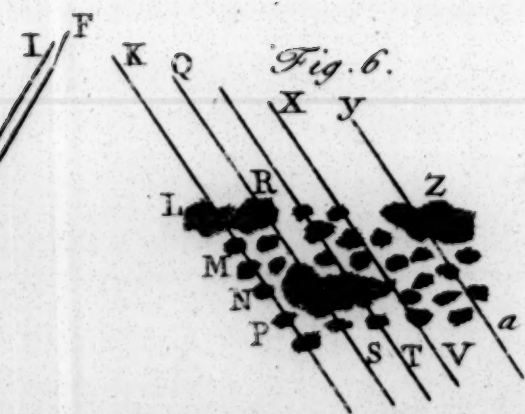
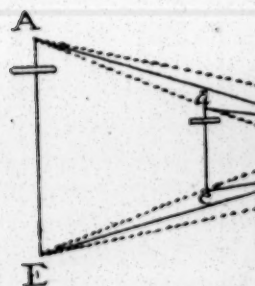
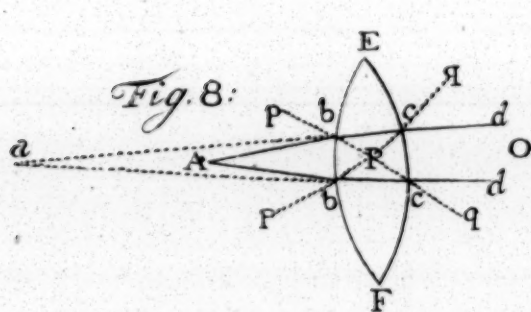
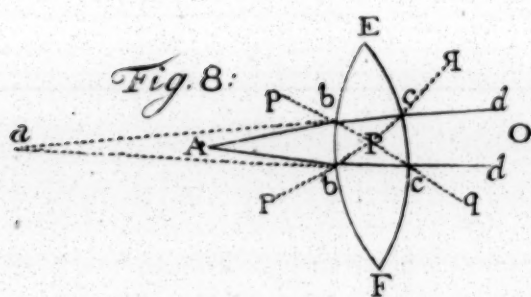
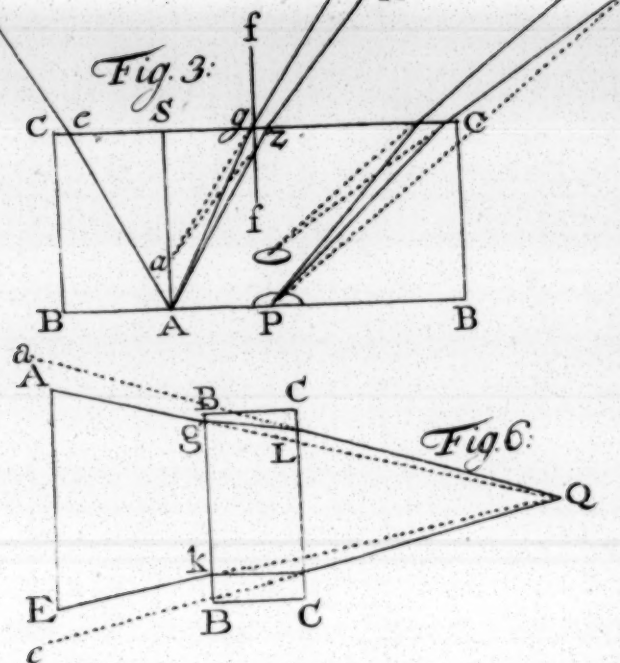
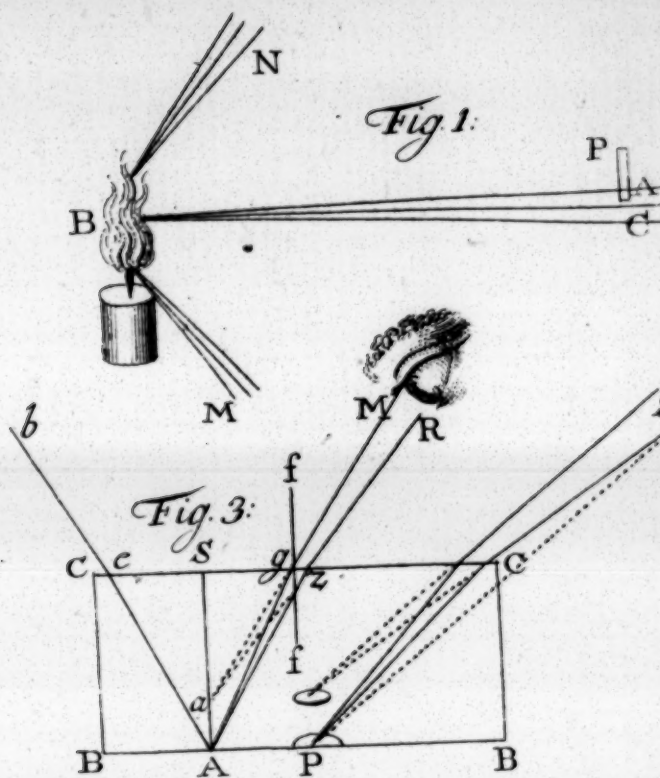


Fig. 7.

Fig. 4.

Fig. 5.





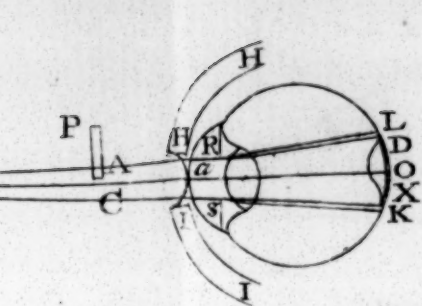


Fig. 2:

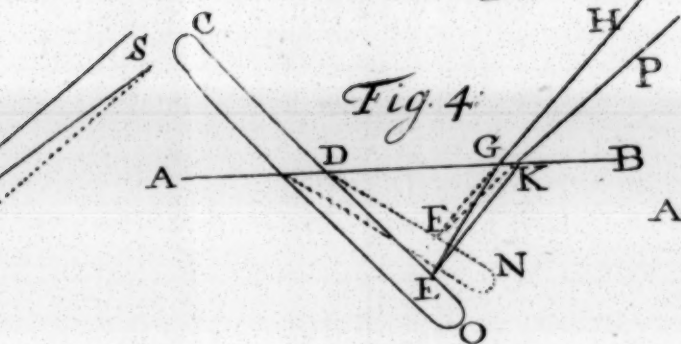
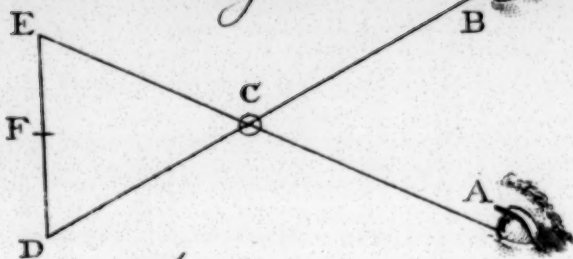


Fig. 4:

Fig. 5:

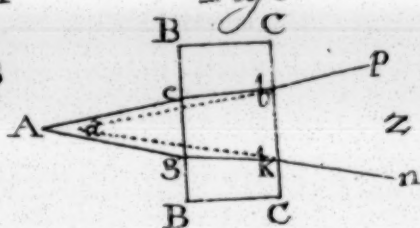


Fig. 6:

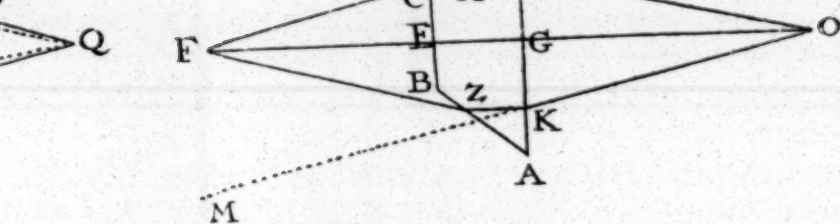


Fig. 7:

Fig. 10:

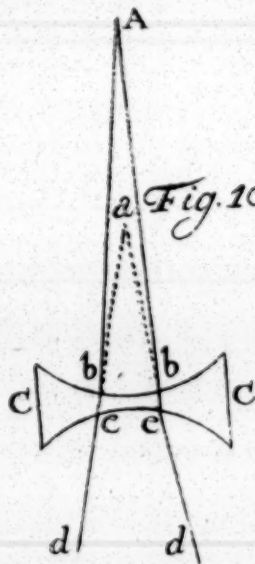


Fig. 9:

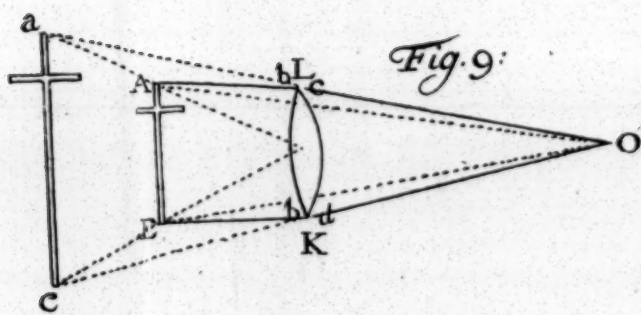


Fig. 11:

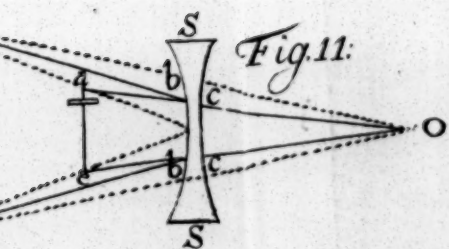


Fig. 12:

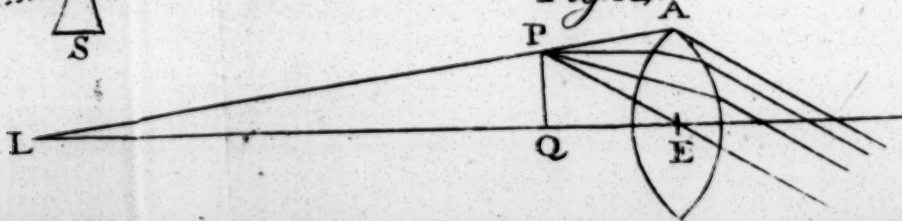


Fig. 1.

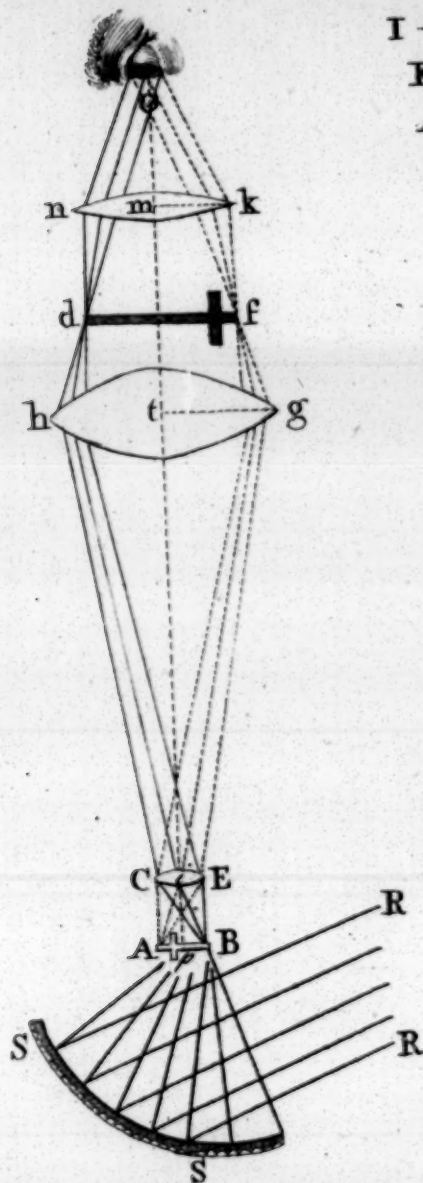


Fig. 2.

Fig. 5.

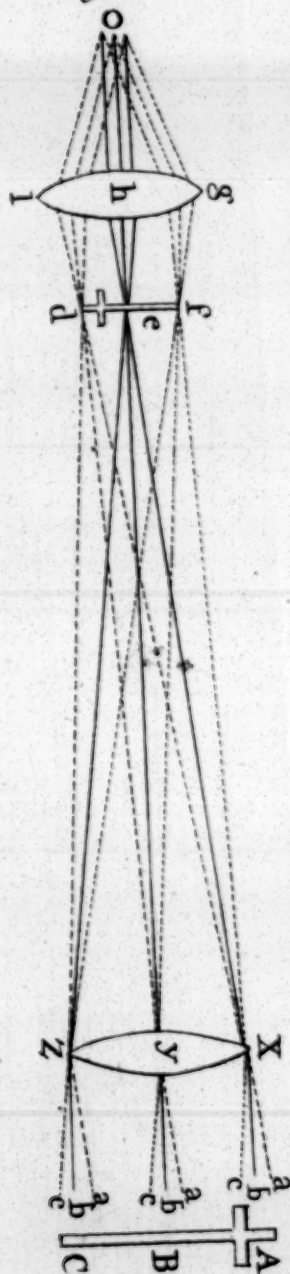
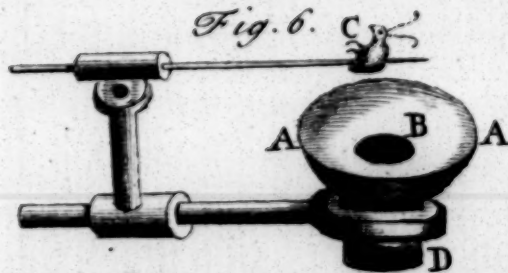


Fig. 6.



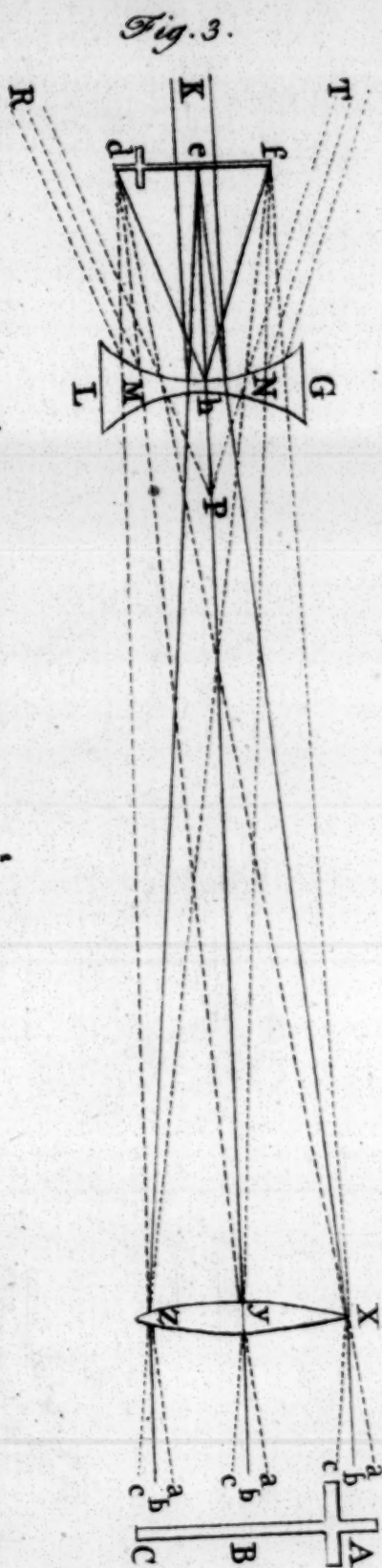
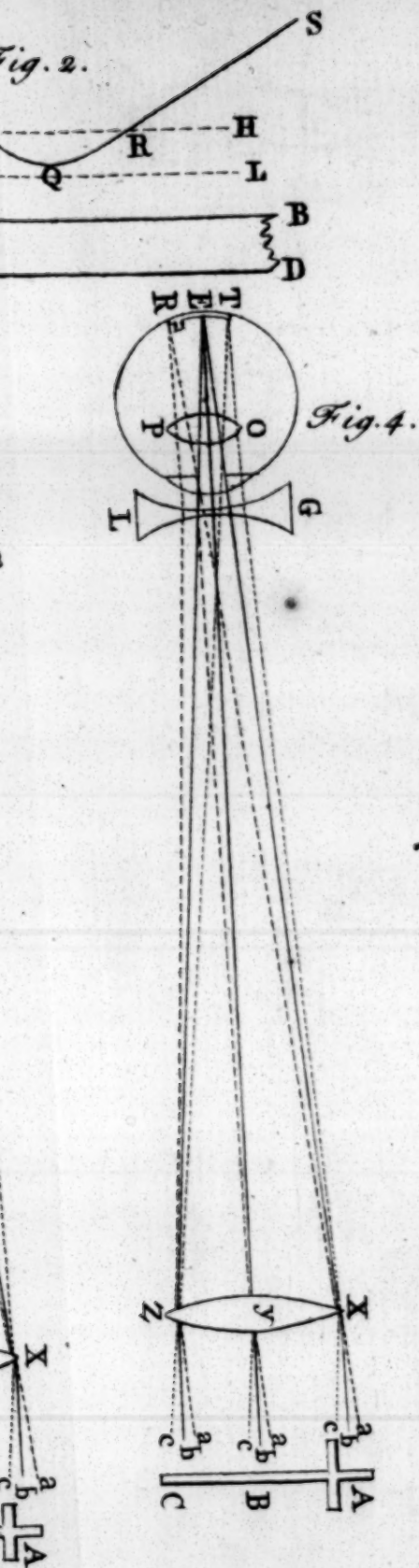


Fig. 1.

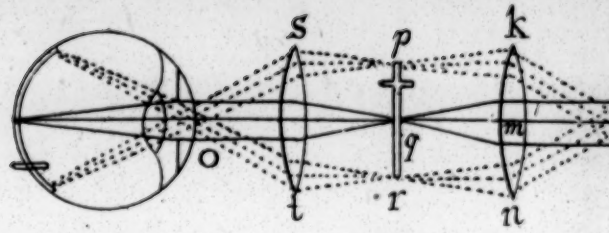


Fig. 2.

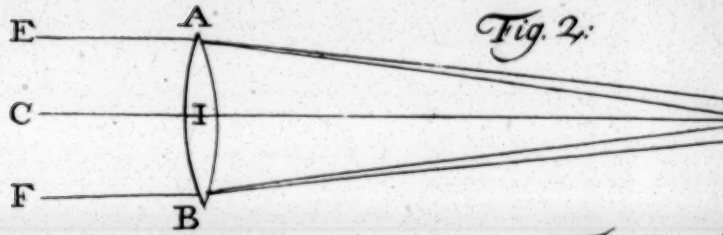


Fig. 4.

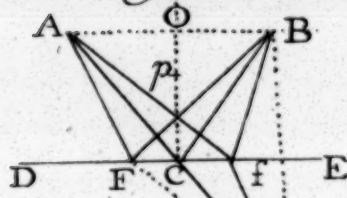


Fig. 5.

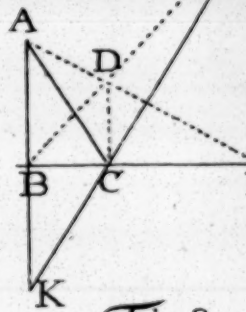


Fig. 7.

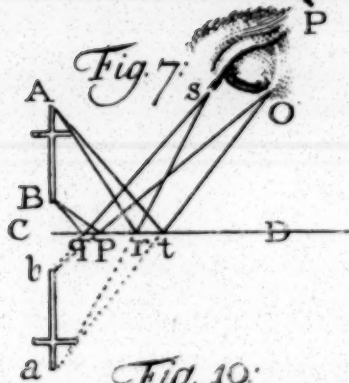


Fig. 8.

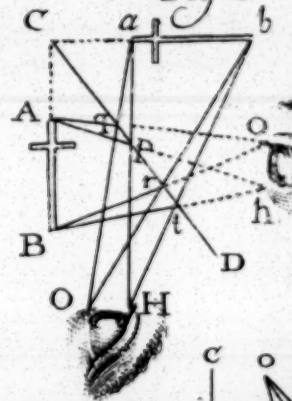


Fig. 10.

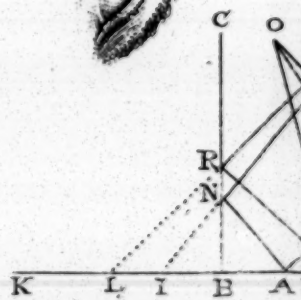
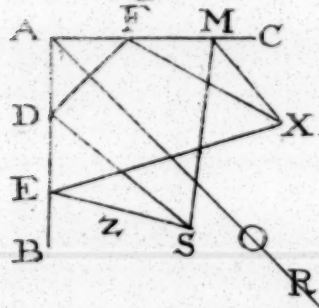
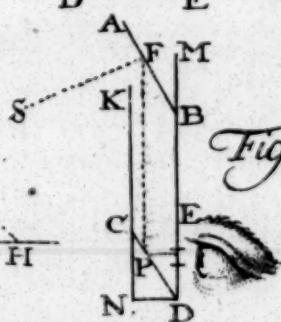
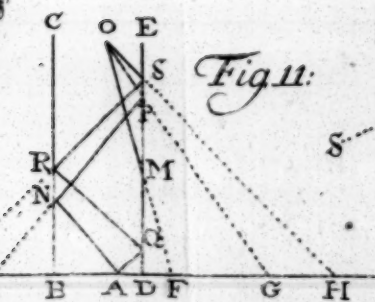
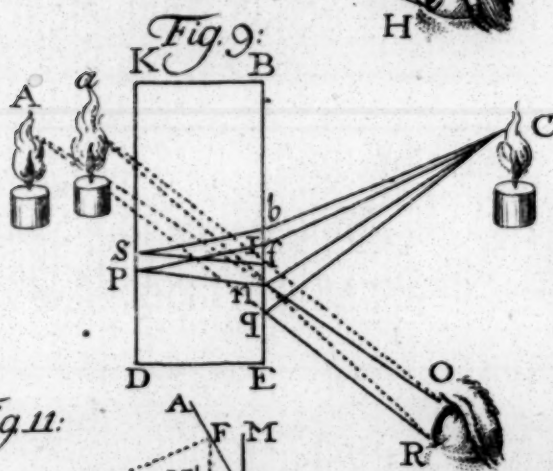
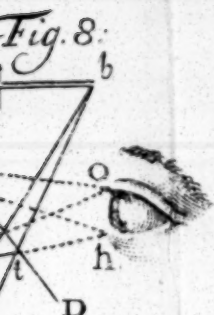
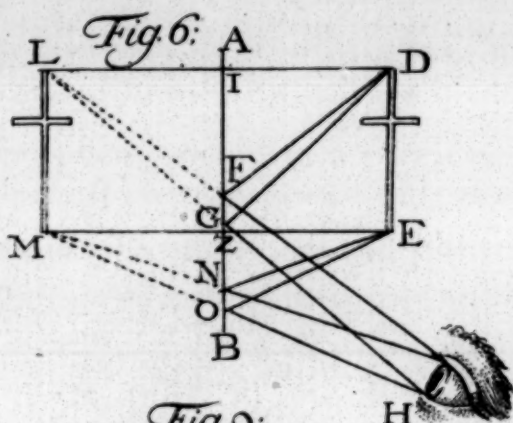
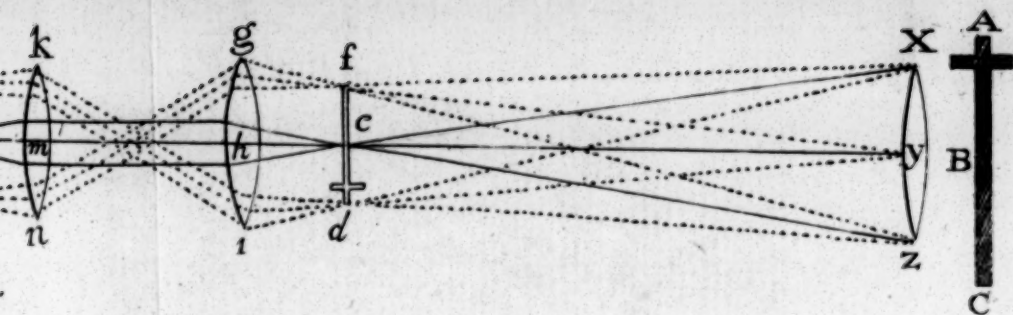
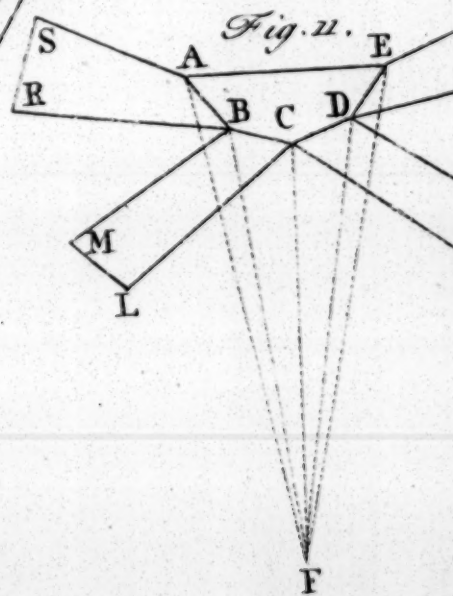
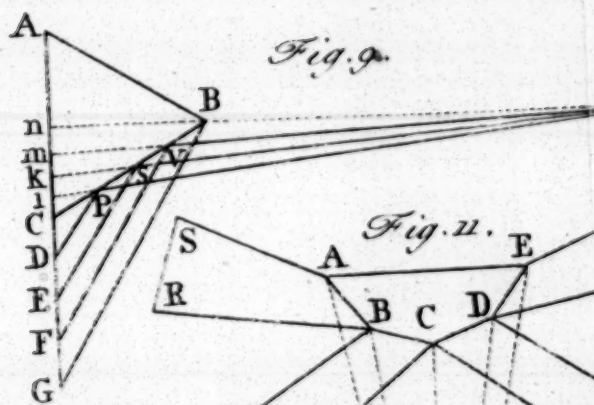
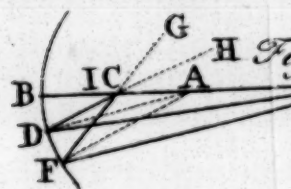
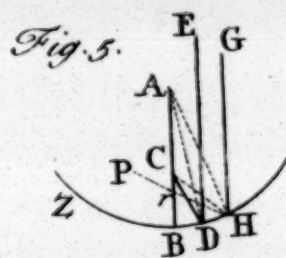
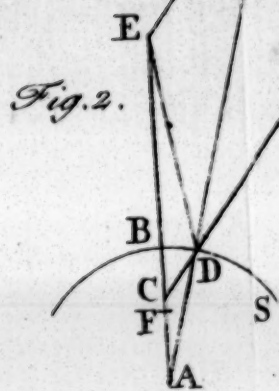
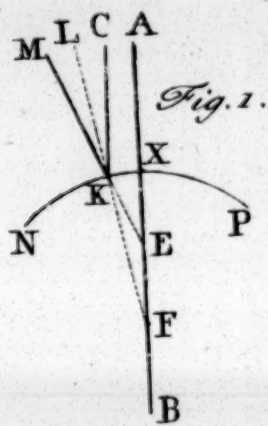
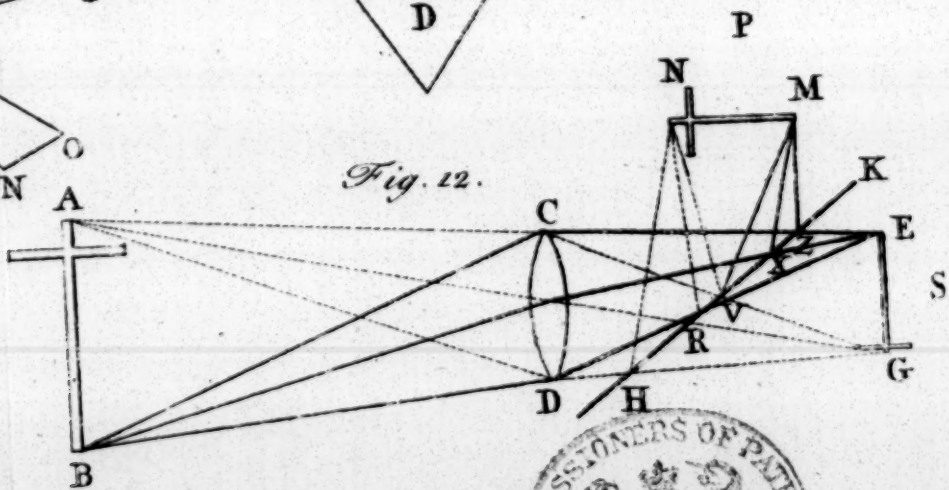
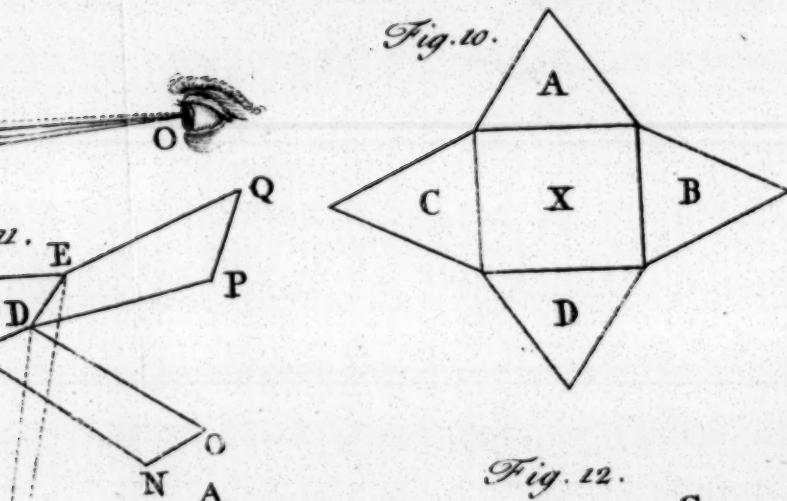
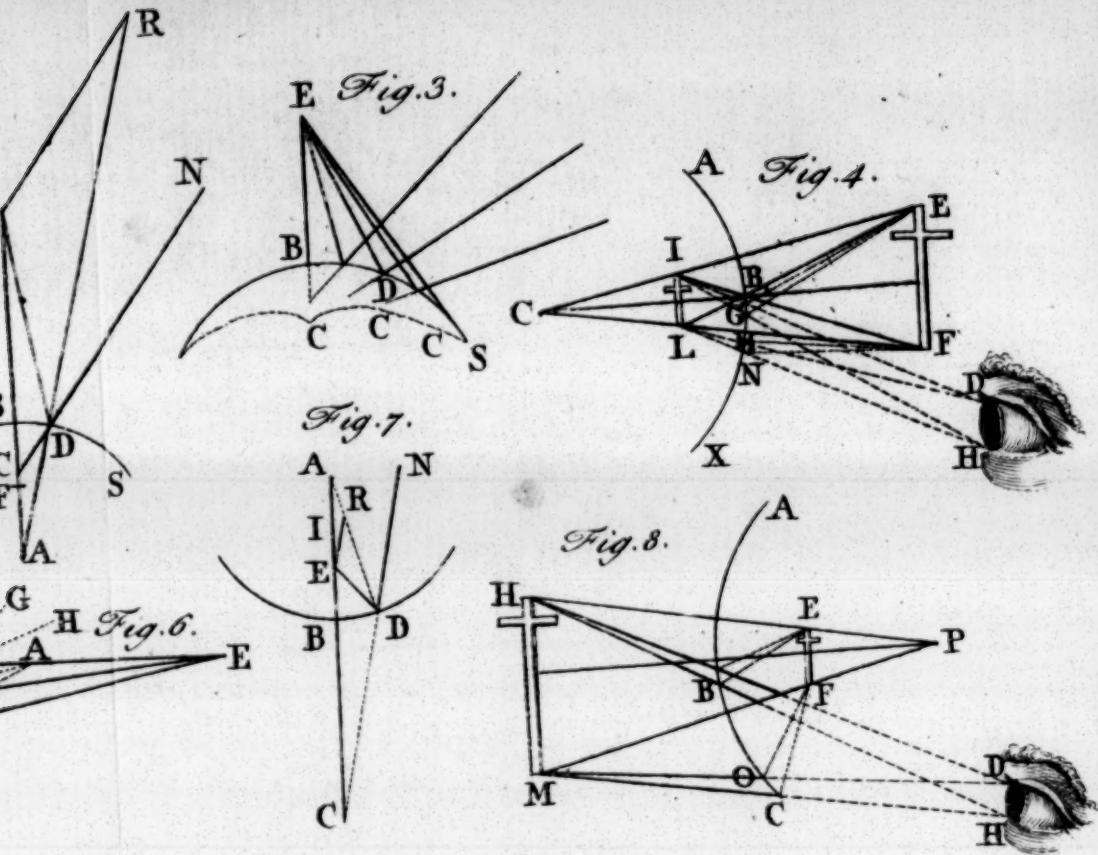
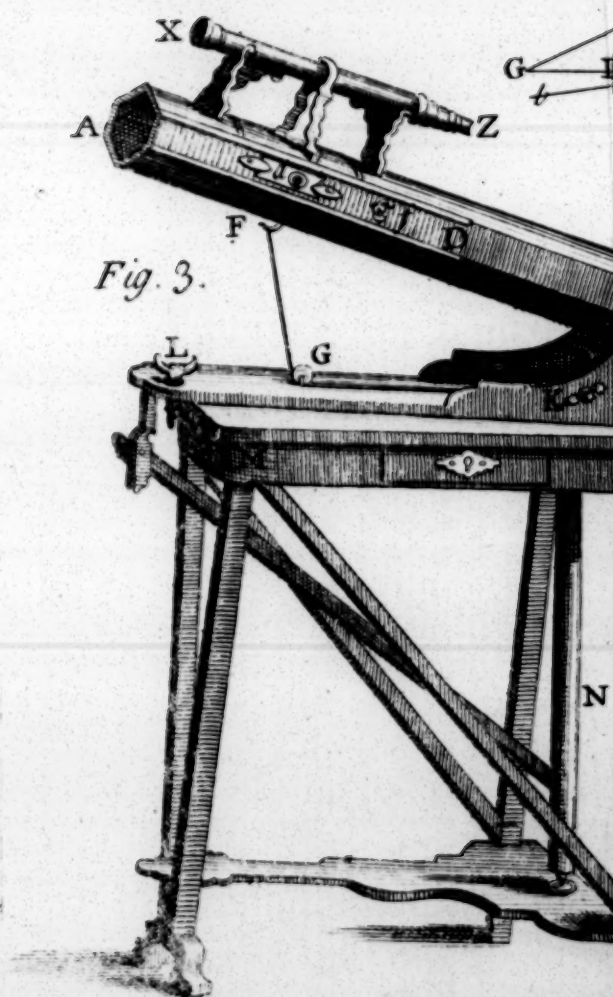
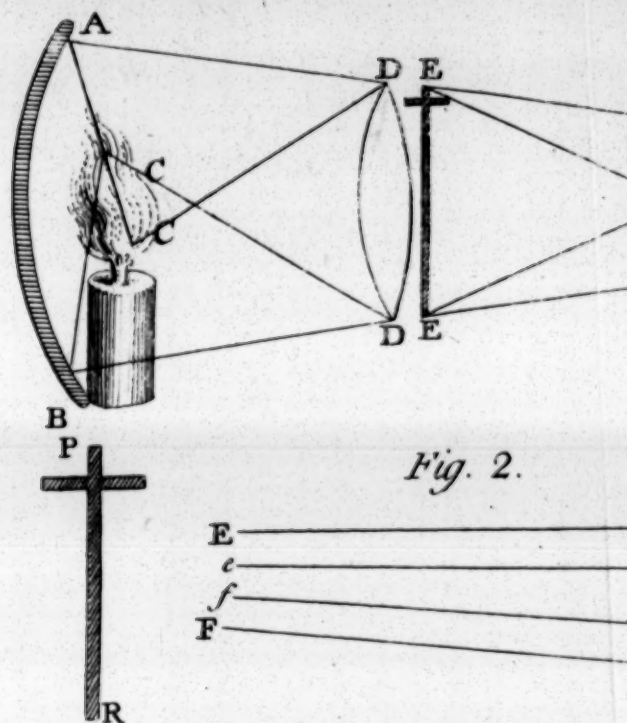


Fig. 1:









Autelli Sculp.

Fig. 1.

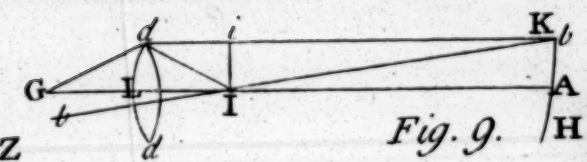
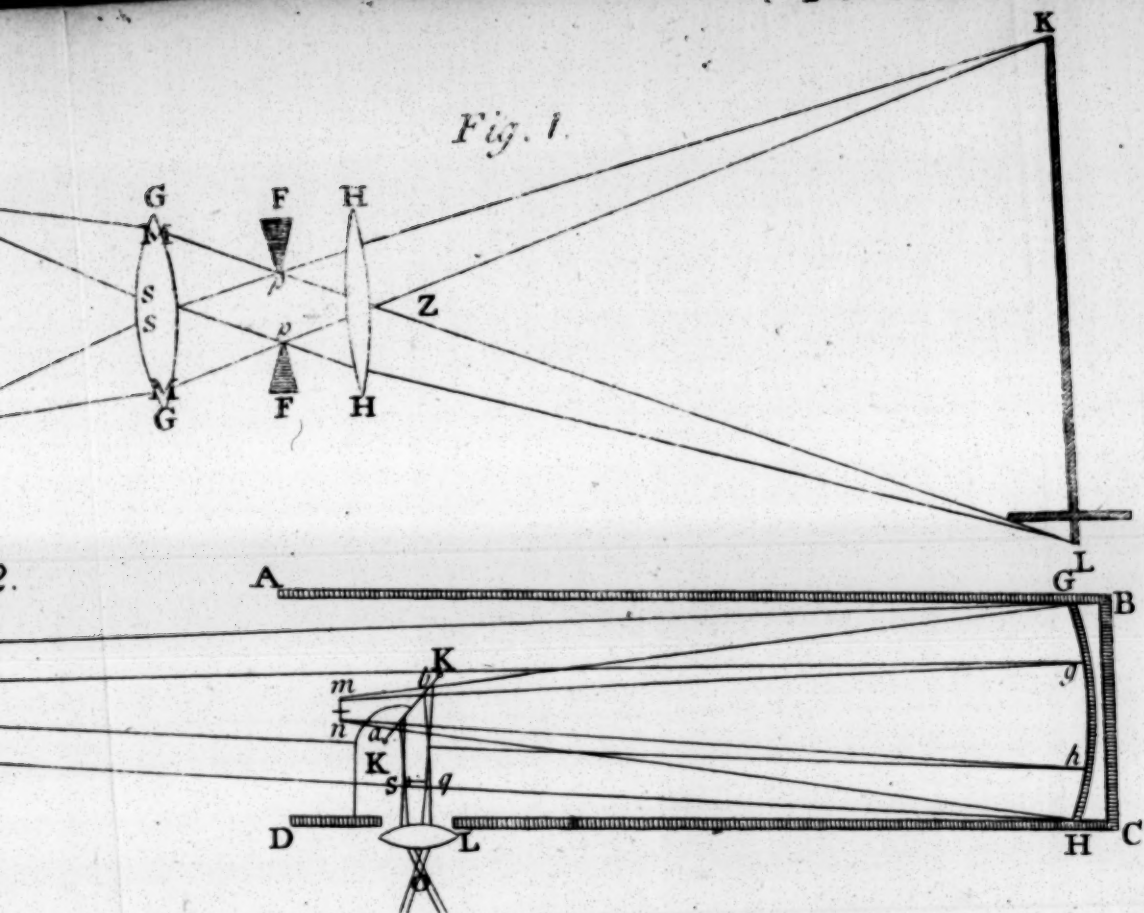


Fig. 9.

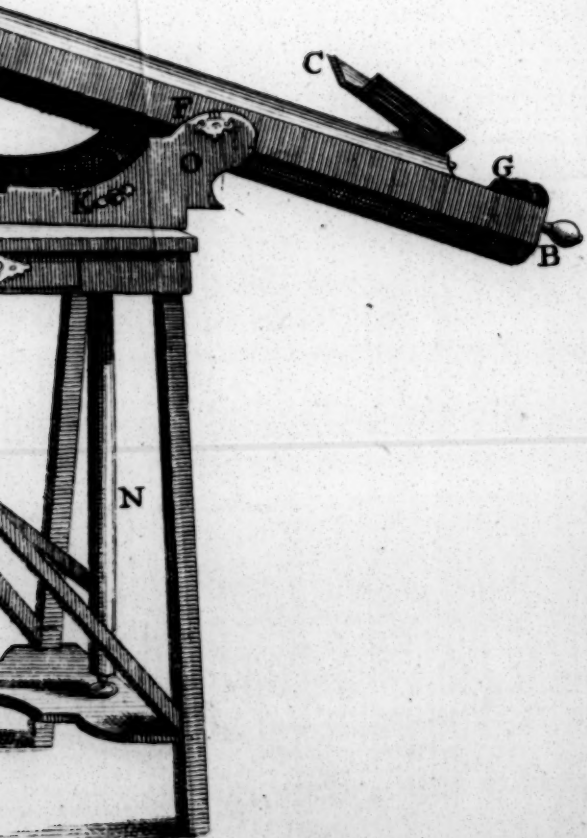


Fig. 4.

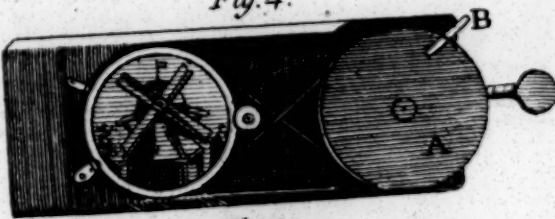


Fig. 5.



Fig. 6.



Fig. 7.



Fig. 8.



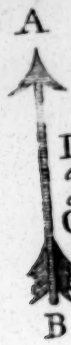


Fig. 1.

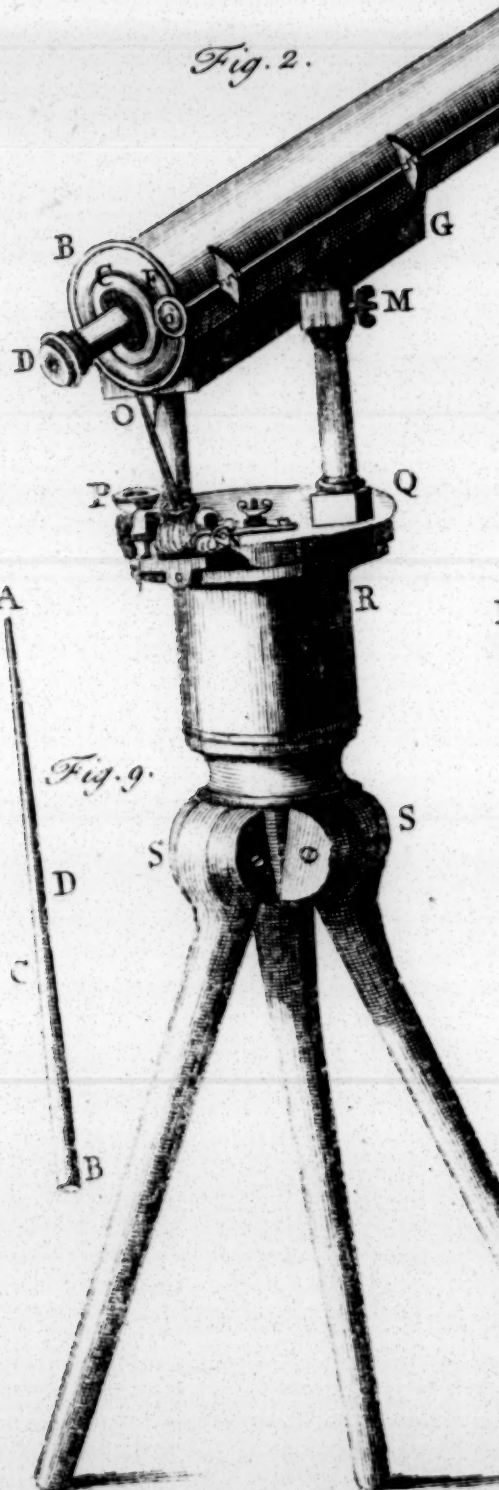


Fig. 2.



Fig. 9.

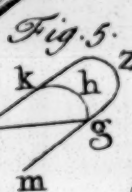
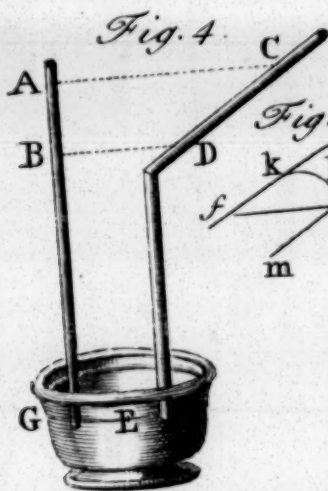
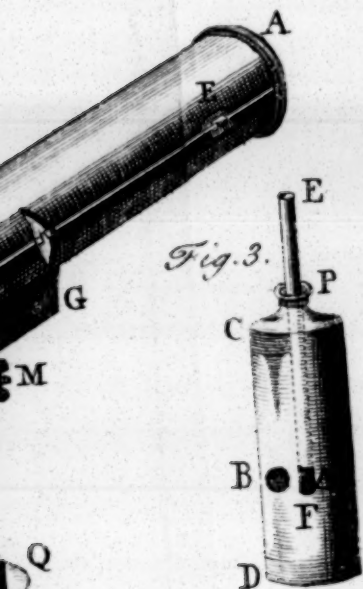
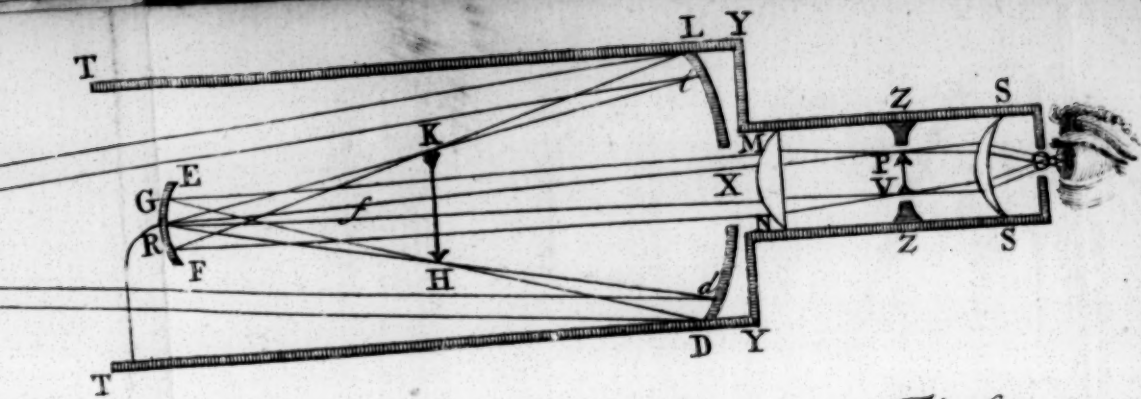


Fig. 6.

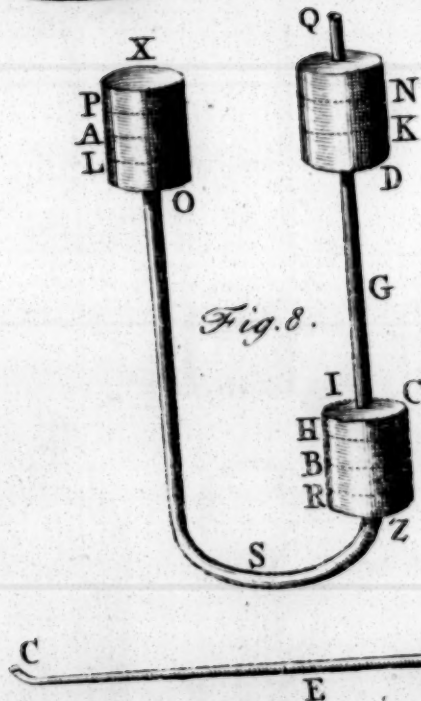
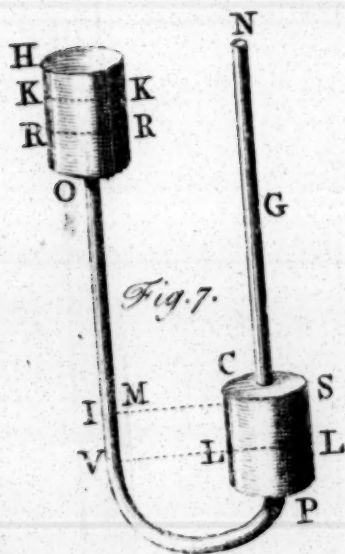
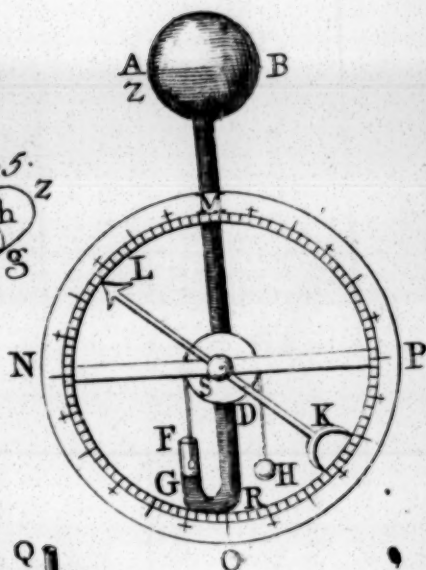
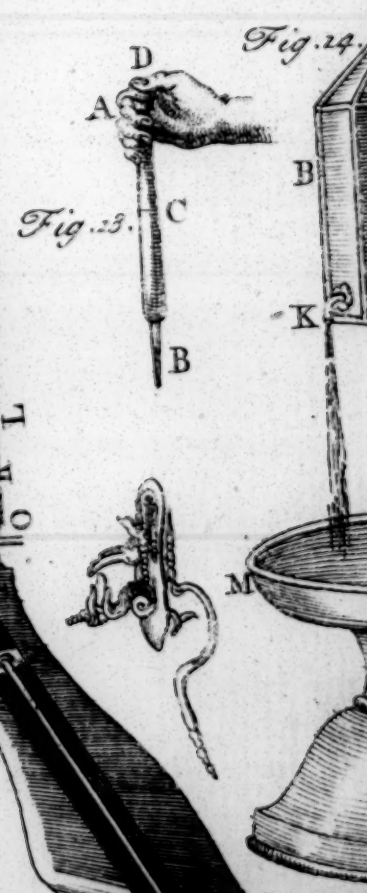
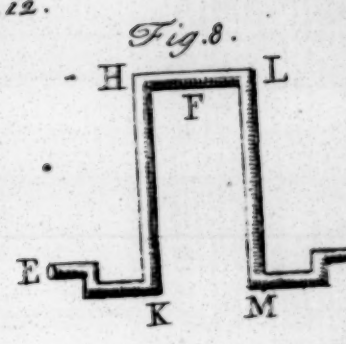
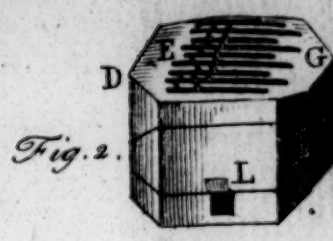


Fig. 10.





PAT

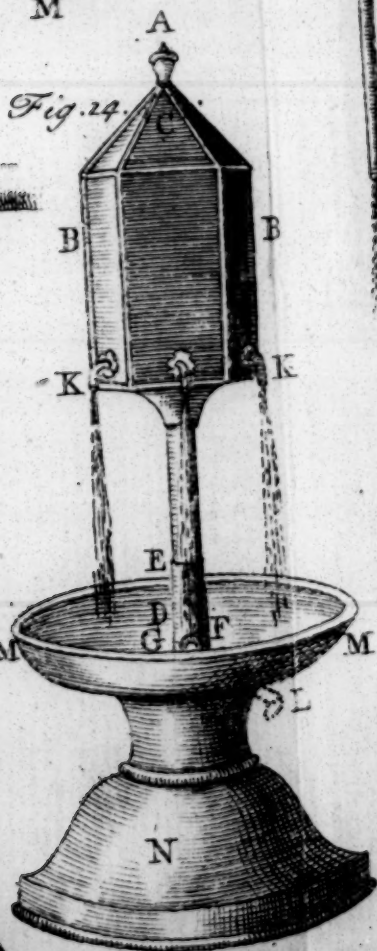
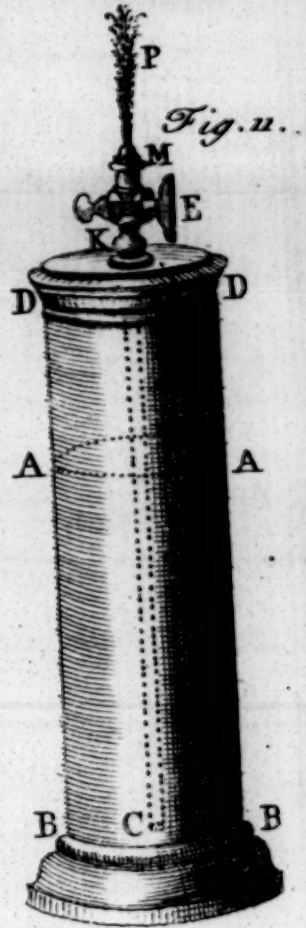
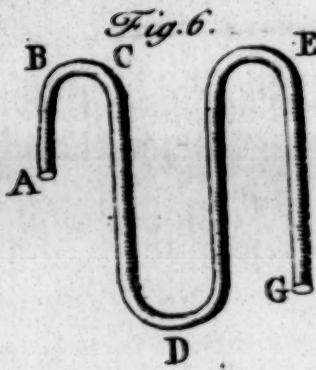
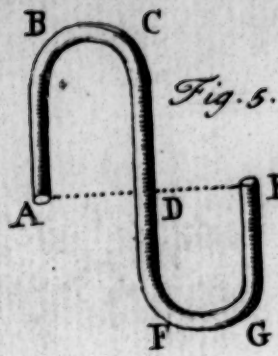
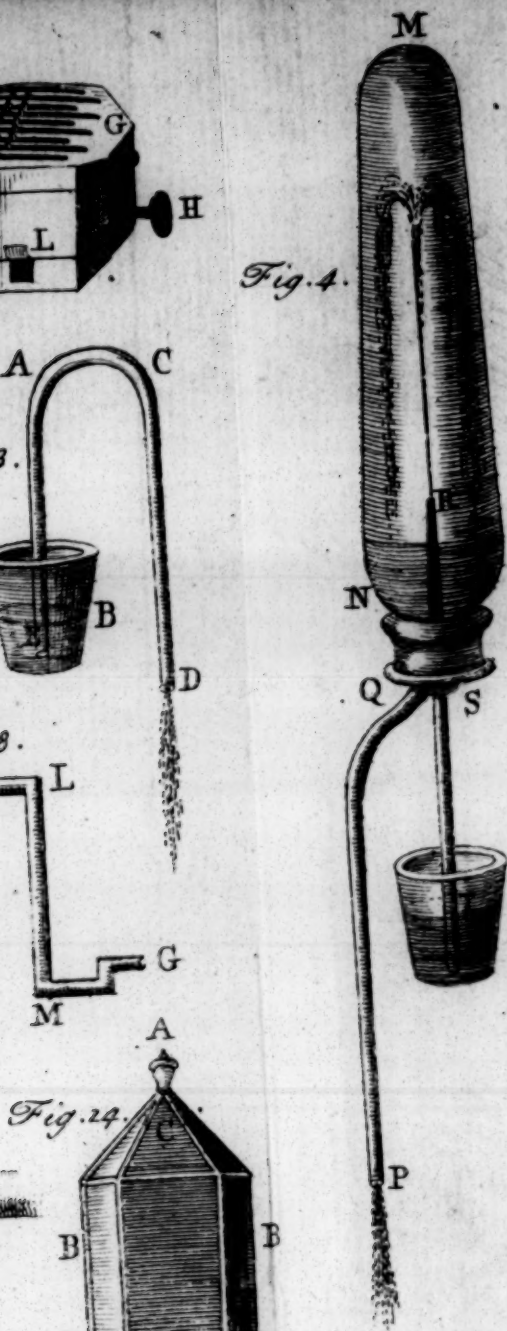


Fig. 1.



Fig. 6.

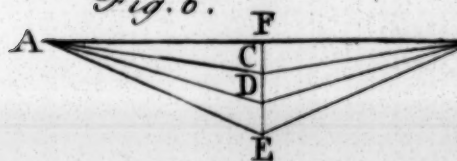


Fig. 9.

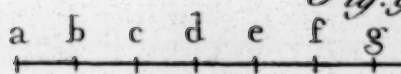
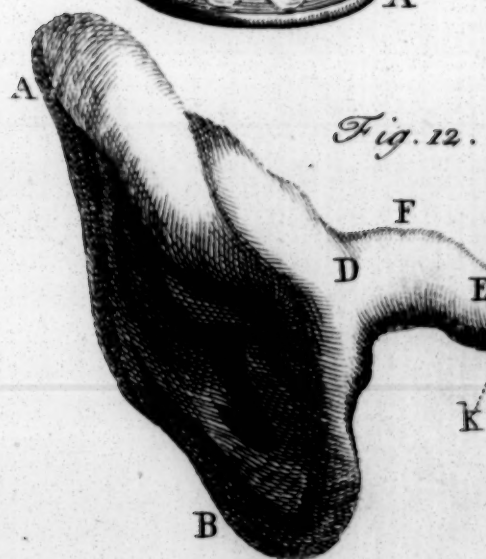


Fig. 10.



Fig. 12.



PATENT

Fig. 2.

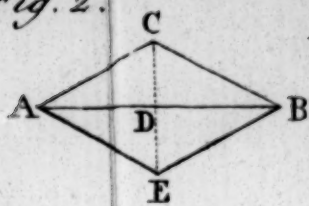


Fig. 3.

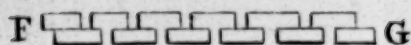


Fig. 5.

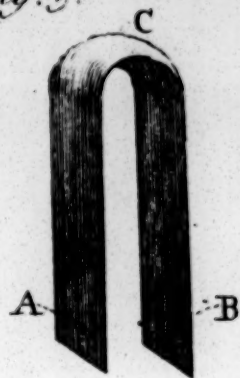


Fig. 4.

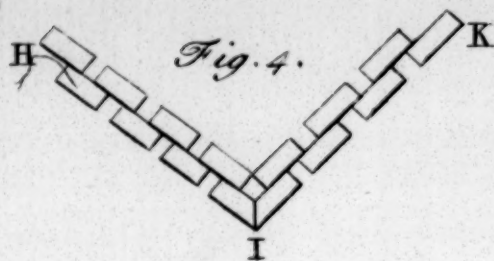


Fig. 7.



Fig. 8.



Fig. 9.

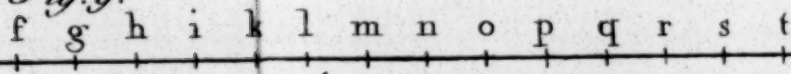


Fig. 11.

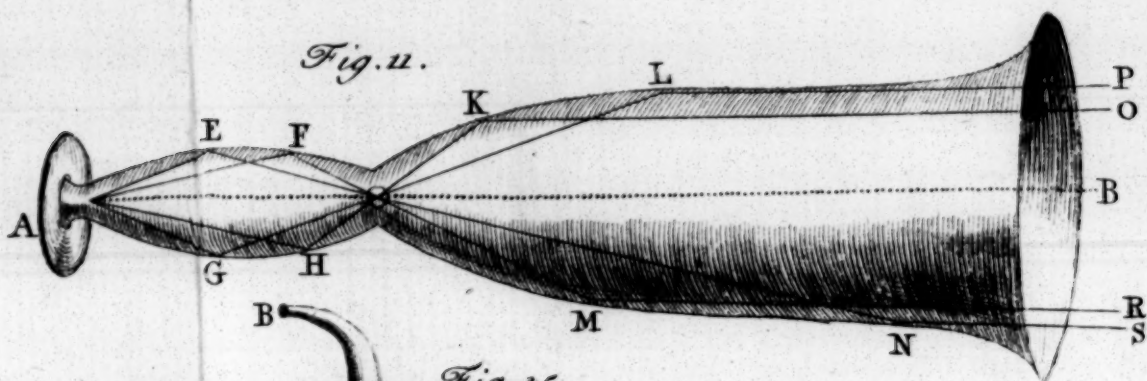


Fig. 15.



Fig. 13.

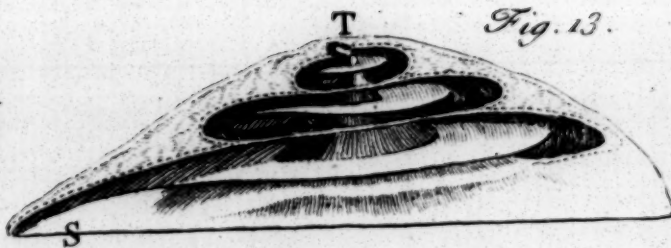


Fig. 14.

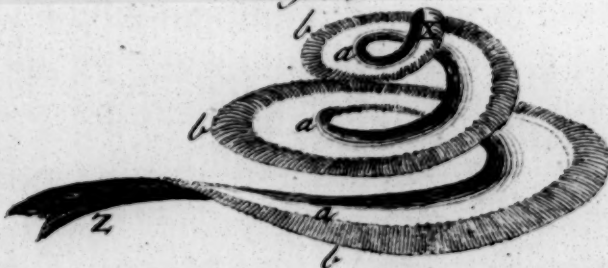
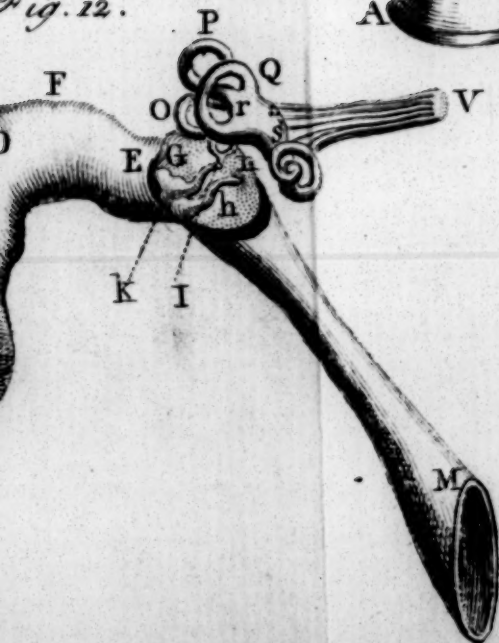


Fig. 12.



A *Fig: 1.* B.....

Fig: 2.

Fig: 3.

Fig: 4.



Fig: 8.

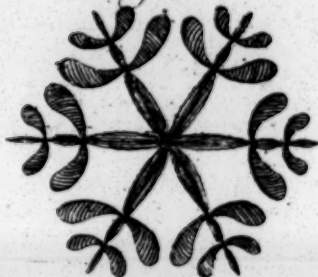


Fig: 9.

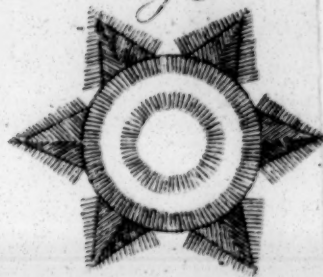


Fig: 12.

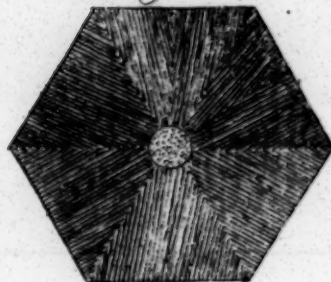


Fig: 13.

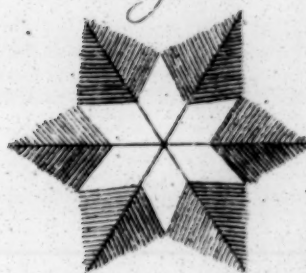


Fig: 17.

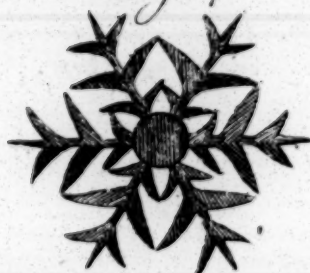


Fig: 18.

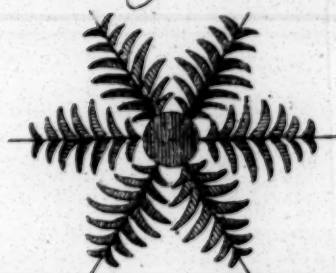


Fig: 21.



Fig: 22.



Fig: 25.

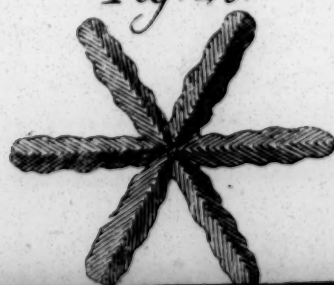


Fig. 4.



Fig. 5.



Fig. 6.



TAB. XXIV.

Fig. 7.



Fig. 10.

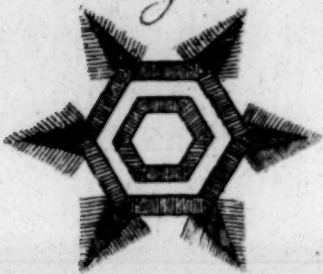


Fig. 11.

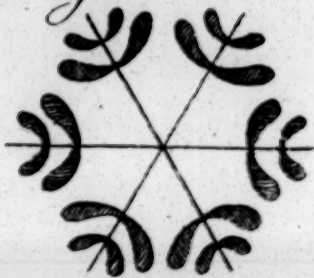


Fig. 14.



Fig. 15.

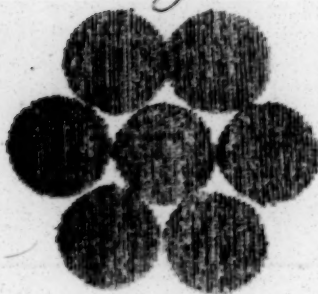


Fig. 16.



Fig. 19.

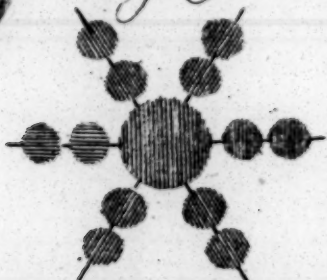


Fig. 20.

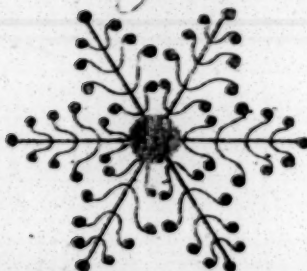


Fig. 23.

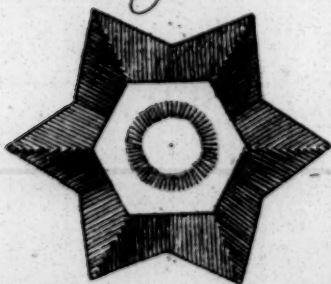


Fig. 24.

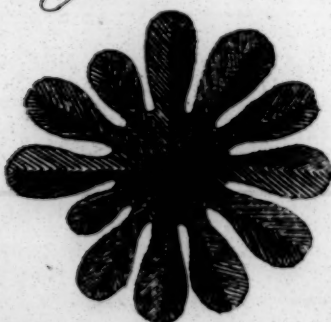
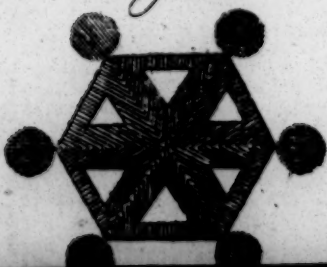
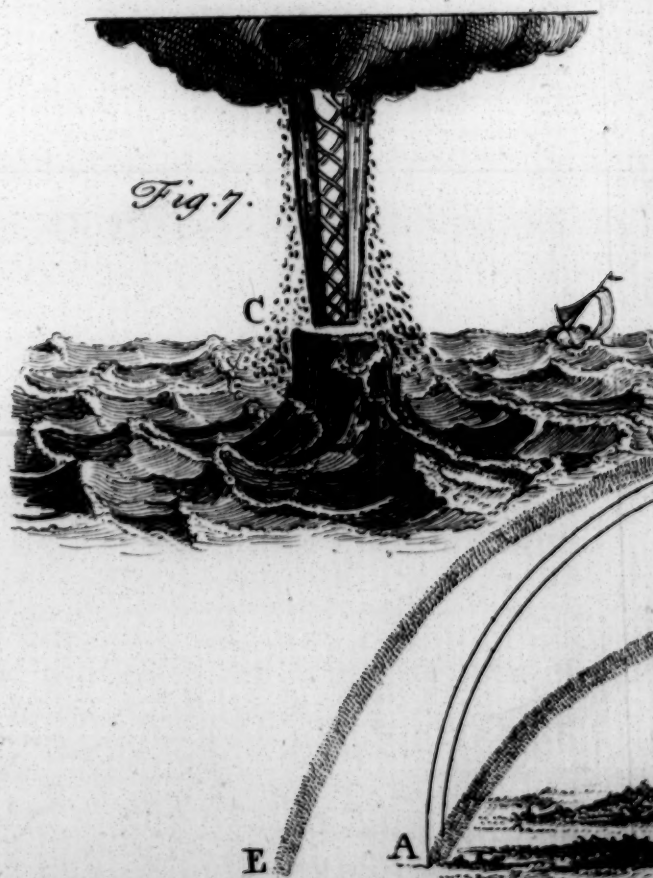
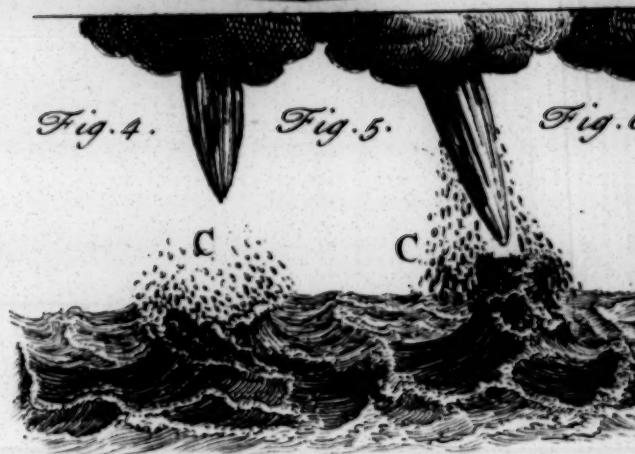


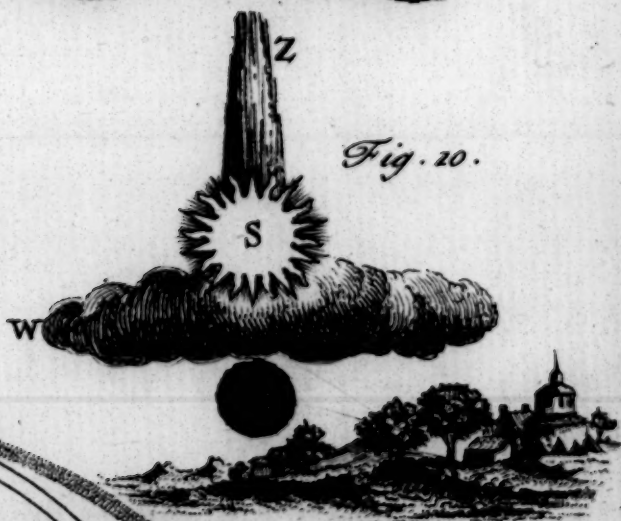
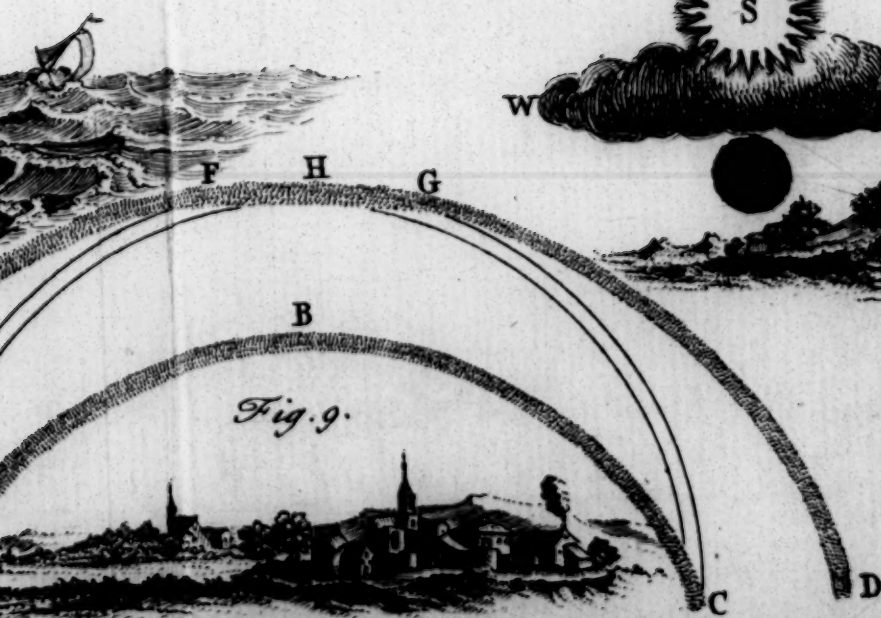
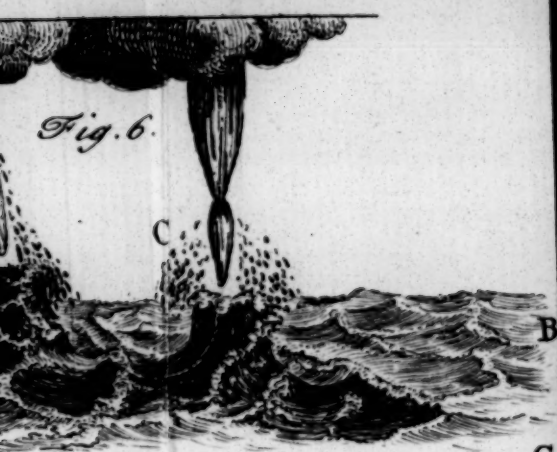
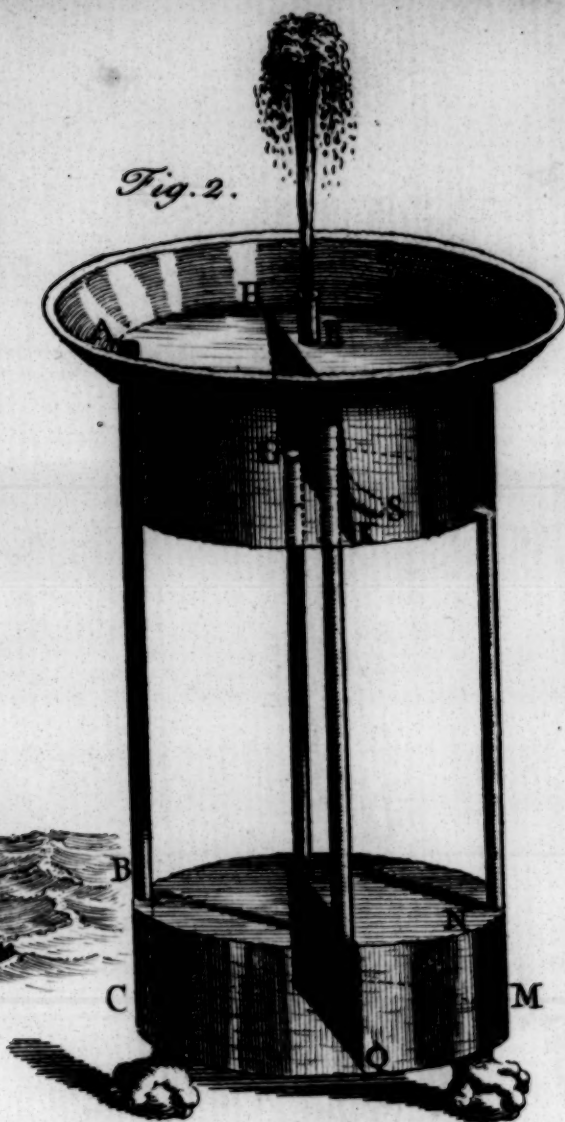
Fig. 27.

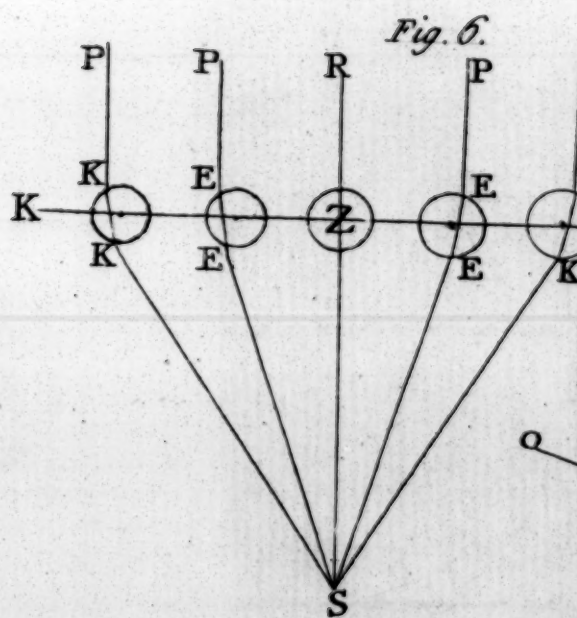
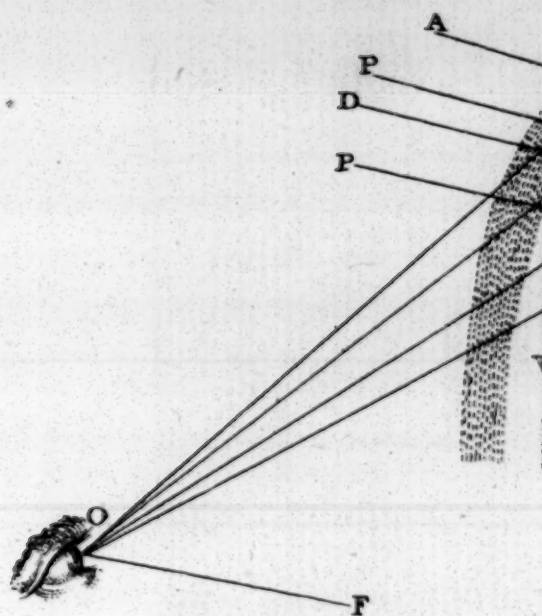
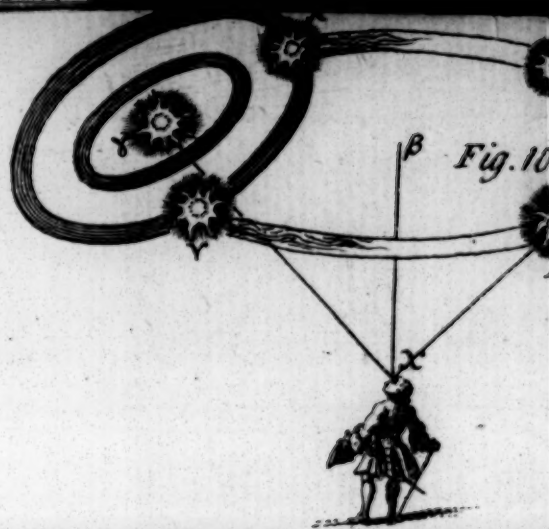


Fig. 26.

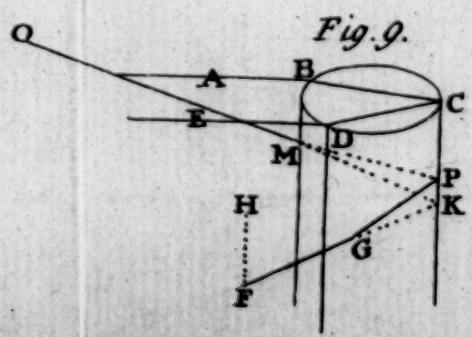
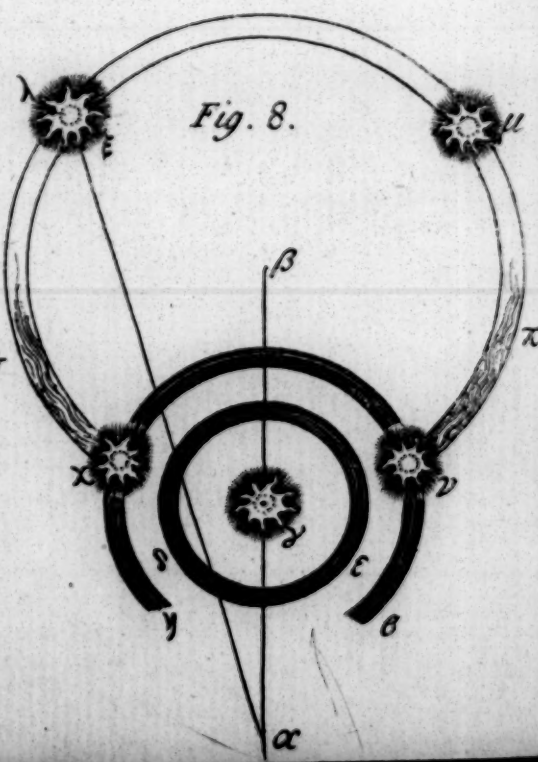
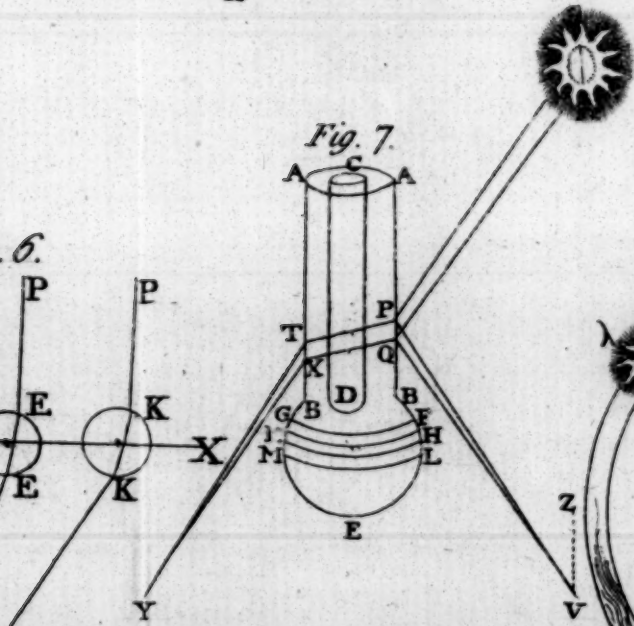
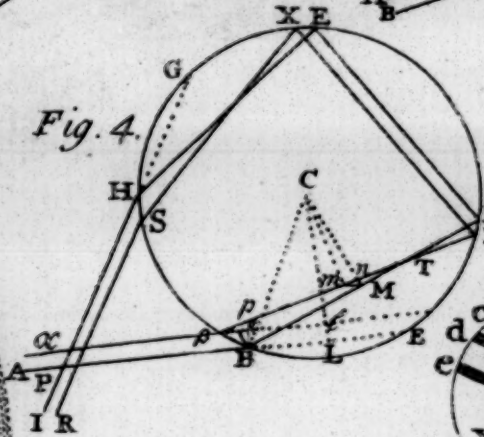
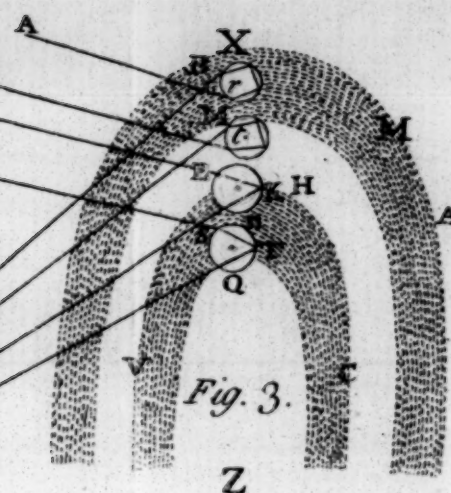
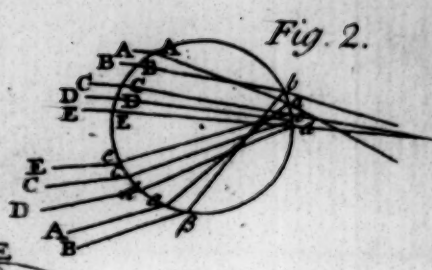
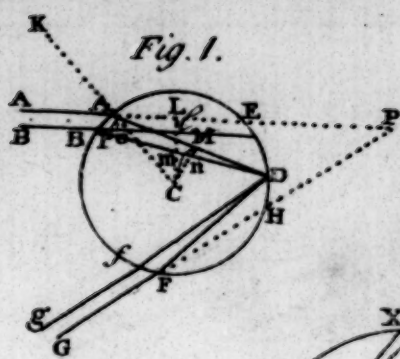








Hulett, Sculp.



PATENT OFFICE LIBRARY



